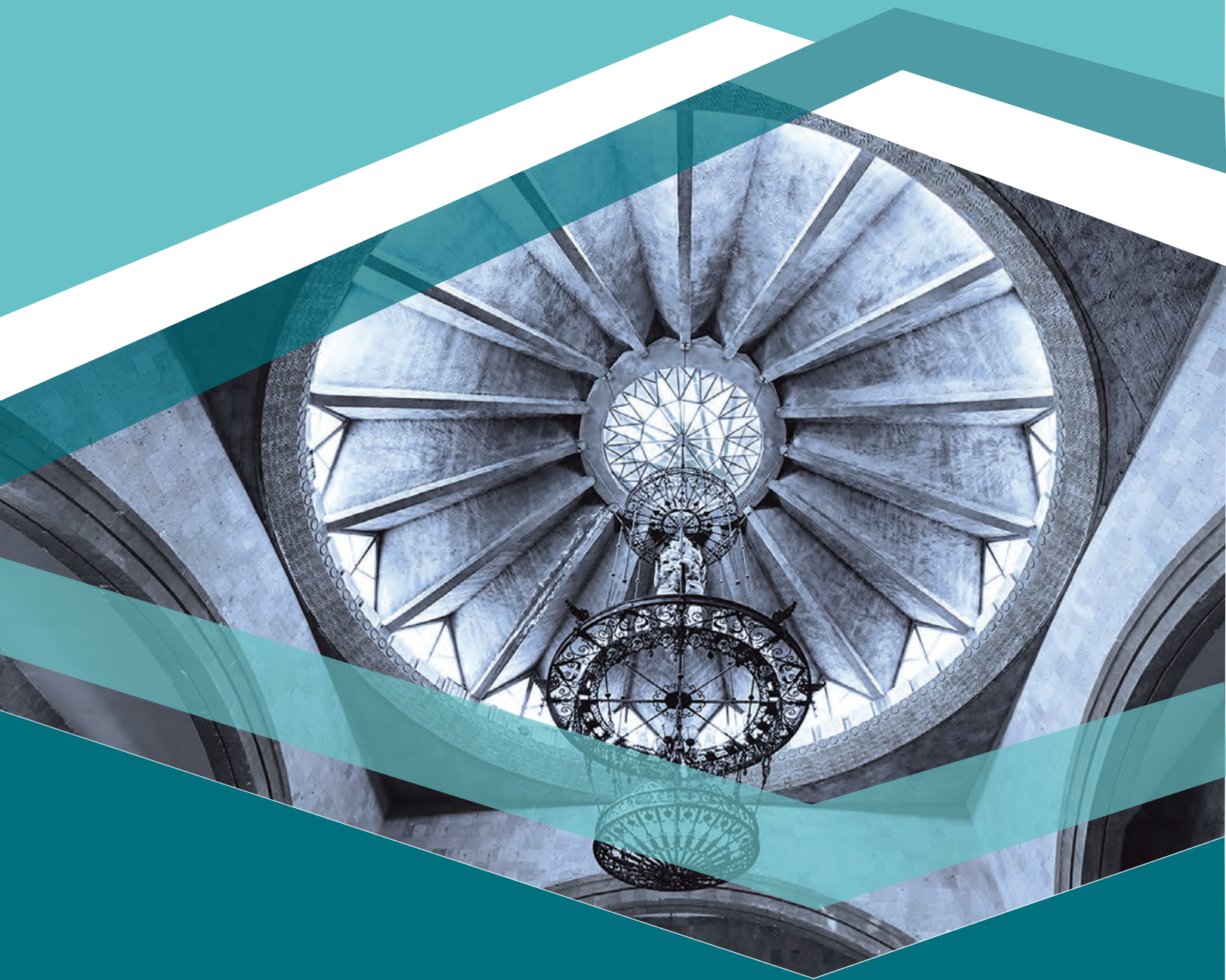
ISSN 2738-2656

2022-2



JOURNAL OF ARCHITECTURAL AND ENGINEERING RESEARCH

The journal is approved for publication by National University of Architecture and Constraction of Armenia Scientific Council

THE MINISTRY OF EDUCATION, SCIENCE, CULTURE AND SPORTS OF THE REPUBLIC OF ARMENIA

JOURNAL OF ARCHITECTURAL AND ENGINEERING RESEARCH

2022 - 2

YEREVAN 2022

Content

DOI: https://doi.org/10.54338/27382656-2022.2-001

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INCREASING THE EFFICIENCY OF FINE-GRAINED LIGHTWEIGHT CONCRETE USING COMPLEX ADDITIVES

This work aims to investigate the physical and mechanical characteristics of high-strength lightweight concrete components on the basis of local porous fillers and complex additives. It is theoretically substantiated and practically proven that with optimal amounts of the complex additives – micro silica and superplasticizer Melflux 5581F, it is possible to obtain concrete with a compressive strength of up to 62 MPa and bending strength of 10.5 MPa, profitably using the microsilica pozzolanic activity and super plasticizer, which favorably changes the nature of porosity. Depending on the water/cement ratio, micro-and macro capillary pores of different origins, as well as other shape pores appear in the cement stone, which significantly affects the physical and mechanical characteristics of the concrete: strength, water absorption, water permeability, frost resistance, durability, etc.

Keywords: *high-strength fine-grained concrete, complex additive, pozzolanic activity, super plasticizer, filler grain size, intergranular void, mobility of concrete mix, structure formation, specific strength, physical and mechanical characteristics.*

Introduction

Concrete is a widely used building material that determines the level of civilization and the construction industry of the country. The volume of concrete used worldwide exceeds 3 billion cubic meters. The interest in this material is due to the simplicity of production technology, ecological safety, reliability of operation, and the possibility of extensive use of local raw materials and anthropogenic waste. The constant interest in concrete and the increase in demand causes a tendency to constantly improve it by using different types of mineral and chemical additives, so the production of such materials is one of the dynamically developing branches of the construction industry. With this approach, it becomes natural to explore other ways to improve the concrete structure using various complex additives, to study the relationship between the properties and the concrete structure [1].

The current level of concrete science makes it possible to develop lightweight concretes of different functionality, among which the concretes based on local highly active lithoid-pumice sand and gravel are also of great interest. The high strength of concrete is directly related to the average density, as one of the most important issues in the construction industry is to provide the required bearing capacity with a possible reduction in the structure mass. The application of structural and high-strength lightweight concrete with flexible or pre-stressed reinforcement should meet higher mechanical characteristics and durability requirements at the normalized average density, which will increase the technical and economic efficiency of the field.

Materials and Methods

Concrete is a capillary porous rock material, where pores include volumes not filled with solid material, regardless of origin. Pores can be formed for a variety of reasons, the most common is the technological porosity conditioned by the processes of concrete mixture compaction (incomplete condensation) and concrete hardening. Today, by introducing various chemical and mineral additives, it is possible to reduce technological

porosity. The mechanisms of action of these materials are different and are of particular interest. The main cause of capillary porosity formation is the evaporation of excess water from the cement mortar, which can be reduced by adding plasticizing additives. The other reason is the usage of mineral additives, which can produce various new formations and fill the voids due to pozzolanic activity while increasing the conglomerate's strength. In other words, mineral additives can participate in structural development, which does not affect the physical and mechanical characteristics of the artificial conglomerates. Due to the synthesis of a high-density cement matrix and dense compaction of fine fillers, design principles for fine-grained high-strength concrete have been developed for monolithic construction which allow to obtain deformation characteristics equivalent to concretes obtained using coarse-grain fillers [2].

The use of complex organic-mineral modifiers [3,4] is the same strategy used to solve the problem of hydraulic fine-grained concrete operational properties.

Fine-grained sand concrete has been widely used recently. In the past, their usage was limited by certain features of structure and properties. In fine-grained concrete, increasing the specific surface area of fillers increases the water need and, as a result, the cement consumption. To some extent, it increases the compression deformations, creeps of concrete, and deformity. Compared to ordinary concrete, fine-grained concrete has low compressive strength, frost resistance, and poor adhesion to the reinforcement. Complex additives improve the physical-technical indicators to avoid the mentioned problems. Due to the use of modifier-based composite binders in concrete technology, the preconditions for the usage of concrete have changed in modern concrete science [5-7]. The properties of such concretes are mainly determined by the type of the binder, the properties of the filler, the particle size and strength, the surface quality, the porosity, e.t.c. [8-10]. Fine-grained concretes are characterized by the absence of a rigid stone structure, a higher specific gravity of the fillers, and sometimes an increased volume of intergranular voids. For that reason, compared to traditional coarse-grained concrete, such concretes require a 20… 40 % higher consumption of cement paste. The strength of the concrete will decrease by reducing the filler sizes and cement consumption. Therefore, clean and coarse grain sands (fineness modulus), and gravel with grain sizes of 5 -10 *mm*, should be used in fine-grained concrete.

High strength for such concrete is possible by providing some conditions deriving from the physical foundations of the concrete structure. The main ones, especially in the case of dense, solid fillers, are the application of a low water-to-cement ratio, the addition of plasticizers, complex additives, reaction-active micro silica, thorough mixing, the provision of more favorable conditions for setting, etc. Increasing the cement consumption and micro-reinforcing favor the increase of the concrete strength. Because of the low water-to-cement ratio and high filler concentration, despite the cement price, the shrinkage of such concrete is not more than in ordinary concrete, and in certain situations it is even less.

According to the interstate standard (GOST 31914-2012), the strength limit of high-strength concrete should not be less than 60 MPa. However, the strength limit of such concrete is very conditional as it is mainly related to the degree of development of science and technology in the production of cement, concrete, and additives. Therefore concretes are conventionally divided into high-strength, special high-strength, and super-strong concretes. LC 50/55 and high grades (according to EN 206-1) are presented for high-strength lightweight concrete.

In addition to enhancing quality, the challenges of increasing the efficiency of construction materials include lowering material and energy prices. As a result of the development of high-rise frame construction, some issues related to the production and use of high-strength lightweight concrete with high mobility were raised. They are due to various problems arising in monolithic house-building technology, such as concrete mix layering by height, disturbance of homogeneity of concrete, formation of cavities due to insufficient compaction of concrete mixture, e.t.c., which inhibit the provision of necessary physical and mechanical characteristics of the structure. Due to the use of various mineral micro dispersion fillers and modifiers, in particular micro silica, ash loss, and other highly-efficient modern modifiers, these negative phenomena were possible to compensate. One of the most universal (effective) methods for modeling the structure and adjusting

the properties of concrete is the introduction of additional components into the concrete mix [11-15]. The combination of superplasticizer with micro silica allows the production of high-strength lightweight concrete or lightweight concrete with traditional strengths, reducing the consumption of cement.

Based on the above, the task was set to study the possible methods of obtaining lightweight high-strength concrete with lithoid pumice sand of Jraber mine, using 42.5 class Portland cement and micro silica. The apparent density of 42.5 class (CEM-I, 42.5N) Portland cement from Ararat Cement Plant used in the study was 1031 kg/m^3, and the residue on the 80-micron sieve was 9.249%. Table 1 shows the results of determining the cement activity by standard methods.

Table 1. Test results of Ararat cement Plant

Cement CEM-I, 42.5N, *g*	450
Multi-grain sand, *g*	1350
Water, *ml*	225
In the case of bending, the tense strength limit at the age of 7 days, *MPa*	4.001
Compression strength at the age of 7 days, *MPa*	43.409
In the case of bending, the tense strength limit at the age of 28 days, *MPa*	6.468
Compression strength at the age of 28 days, *MPa*	48.366

The fineness modulus of lithoid sand was M_k = 3.02, and the apparent density was 1148.6 kg/m^3. The granular composition of lithoid sand is shown in Table 2. The apparent density of micro silica is 314.5 kg/m^3.

Table 2. Granular composition of lithoid sand

Sieve hole sizes, *mm*	5	2.5	1.25	0.63	0.315	0.16	< 0.16
Total residue, *%*	0	38.605	11.715	10.64	10.015	10.35	18.675

Microsilica particles, having an extremely fine and amorphous structure, increase the water demand of the concrete mix. That's why superplasticizers were also used. The quantity of micro silica adjusted within 5–30 percent of the cement mass throughout processing, and 0.45 percent superplasticizer Melflux 5581*F* was used (Table 3, Fig.).

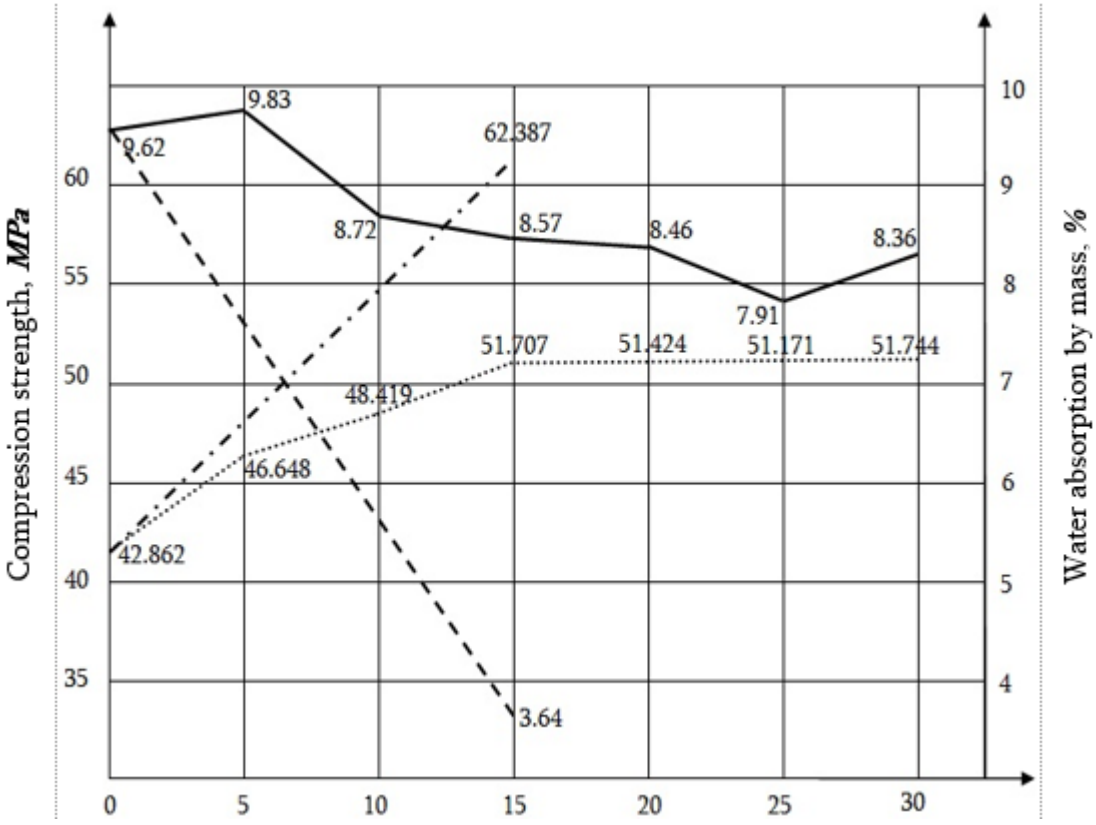
Table 3. Characteristics of lightweight concrete mix

N	Lithoid pumice sand, *kg*	Ararat cement CEM-I 42.5N, *kg*	Micro silica, *kg*	Water, *l*	Superplasticizer Melflux 5581F, *kg*	Density of freshly made concrete, kg/m^3	Slump, *cm*
1	1000	425	-	290	-	1975.3	5
2			21.25 (5 %)	295	-	1979.2	6
3			42.5 (10 %)	305	-	1971.4	6
4			63.75 (15 %)	315	-	1963.5	5
4′			63.75 (15 %)	330	-	1931	8
5			85 (20 %)	325	-	1945.3	6
6			106.25 (25 %)	335	-	1954.4	6
7			127.5 (30 %)	340	-	1932.3	4
8			63.75 (15 %)	260	1.9125 (0,45%)	1978	4
9			63.75 (15 %)	315	1.9125 (0,45%)	1897	17

In Table 4 the lightweight fine-grained concrete experiment results are shown.

Table 4. Characteristics of lightweight concrete

N	Density in a dry state, kg/m^3	When bending, tense strength limit at 7 days, *MPa*	Compression strength at 7 days, *MPa*	When bending, tense strength limit at 28 days, *MPa*	Compression strength at 28 days, *MPa*	Effect of micro silica on the increase in compressive strength, *%*	Water absorption by mass, *%*
1	1871	3.586	38.414	6.445	42.862	-	9.62
2	1905	3.919	41.940	7.445	46.648	8.83	9.83
3	1847	4.242	39.381	3.672	48.419	12.96	8.72
4	1865	5.336	40.303	3.678	51.707	20.63	8.57
4′	1852	5.982	45.882	5.466	46.990	2.41	10.4
5	1857	4.974	38.458	4.154	51.424	19.97	8.46
6	1931	6.801	38.890	6.758	51.171	19.38	7.91
7	1832	5.854	42.163	7.34	51.744	20.72	8.36
8	1862	6.752	43.665	10.567	62.387	45.55	3.641
9	1831	4.232	31.511	7.239	48.742	13.71	3.890



..... the limit of the compression strength depending on the quantity of microsilica,

– · – the limit of the compression strength depending on the quantity of microsilica (15%) and superplasticizer (0.45 %),

—— water absorption depending on the quantity of microsilica,

– – – water absorption depending on the quantity of microsilica (15 %) and superplasticizer (0.45%)

Fig. *Variation of physical and mechanical properties of crushed concrete depending on the number of types of additives used*

The pozzolanic reaction of micro silica increases the hydration process of calcium silicate and causes explicit changes in the concrete structure porosity, thus reducing capillary porosity and increasing gel content, giving the concrete two main properties: improved strength and increased permeability.

The experimental results show that within 5… 30% consumption of microsilica, the strength of concrete, depending on the mass of microsilica, is not monotonous. Furthermore, in the case of the same number of other components, an increase in water consumption from 315 to 330 liters causes a decrease in strength from 51.707 to 46.99 *MPa.*

The experiments were carried out using the specified 4 and 4' compositions, in which Melflux 5581*F* superplasticizer was added by 0.45 percent of the cement mass in both cases, taking into account the fact that the quantity of micro silica of more than 15% does not cause significant changes in the strength. If the mobility of the concrete mix was almost unchanged (CS = 4), a significant increase in concrete strength was observed (20.65%). In the case of an unchangeable amount of water (CS = 17*sm*), the increase in concrete strength decreased significantly (3.72 %).

Based on the selected quantities of a binder, water, and Jraber mine perlite sand, using micro silica and Melflux 5581*F* superplasticizer, it was possible to obtain high-strength lightweight concrete with a strength of 62.387 *MPa,* which is not available for ordinary lightweight concrete.

Conclusion

As a result, a constructive lightweight concrete with a higher structural quality coefficient was obtained, which at the age of 28 days was characterized by a compressive strength limit of 48.742 – 62.387 *MPa* at normal compaction and an average density of 1862 – 1829 kg/m^3 in the dry state.

The developed concrete is a lightweight concrete of constructive significance with high operational properties that can be used in residential and public construction, high-rise buildings, bridges, reinforced concrete multi-layered items (farms, beams, cross-bars), etc. This type of concrete will significantly expand the architectural solutions available for construction. By reducing the mass of elements in the structure, the range of applications for lightweight concrete as a constructive material will be expanded.

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Received: 22.12.2021
Revised: 09.03.2022
Accepted: 25.04.2022

DOI: https://doi.org/10.54338/27382656-2022.2-002

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EFFICIENCY OF USING GEOINFORMATION SYSTEMS IN THE DESIGN OF GAS DISTRIBUTION AND GAS CONSUMPTION NETWORKS

The scientific article is devoted to determining the effectiveness of the use of geoinformation systems (GIS) in the design of gas distribution and gas consumption networks. An experiment was carried out on a laboratory stand modeling ring, dead-end and mixed gas networks. The electronic model of a gas network identical to the laboratory stand in the ZuluGaz 10.0 software package, a module for expanding the GIS functionality for calculating gas supply networks designed to solve various industry. A comparative analysis of the results of an experiment and the results obtained during simulation in GIS is carried out. Based on the analysis, a conclusion is made about the accuracy of the GIS results and the feasibility of using GIS for the design of gas distribution and gas consumption systems.

Keywords: *gas supply, gas distribution and gas consumption networks, design, simulation, experiment, geoinformation systems, hydraulic calculation.*

Introduction

Currently, geoinformation systems (GIS) are widely used in all fields of activity and continue to improve, expanding their functionality and introducing new algorithms into the logic of calculations [1]. The use of geoinformation systems in the design of gas distribution and gas consumption networks under construction and improvement of existing ones is highly justified [2]. However, the characteristics of the electronic model cannot completely coincide with the current gas distribution and gas consumption network.

In the laboratory of the Department of Environmental Engineering of the Don State Technical University, a study was conducted to assess the effectiveness of using one of the most common geoinformation systems in the field of gas supply to settlements. Thus, the GIS ZuluGaz 10.0 was chosen as the object of the study.

Materials and Methods

The research method is based on a comparative analysis of the results of an experiment and an electronic model of the gas distribution and gas consumption system [3].

To solve this problem, a laboratory stand has been developed in the laboratory of the Department of Environmental Engineering of the Don State Technical University to perform scientific research. This stand models gas distribution and gas consumption systems with a gas supply source and consumers located at different distances from the gas supply source [4]. The same gas distribution and gas consumption system was simulation in ZuluGaz 10.0, a GIS functionality extension module for calculating gas supply networks designed to solve various industry tasks.

During the experiment, three types of gas networks were modeled on a laboratory stand: dead-end, ring and mixed (Figures 1, 2, 3) [5-8]. Then, in ZuluGaz 10.0, models of gas networks similar to the stand were modeled and calculated [8-10].

The simulation results in ZuluGaz 10.0 are shown in Figures 1, 2 and 3.

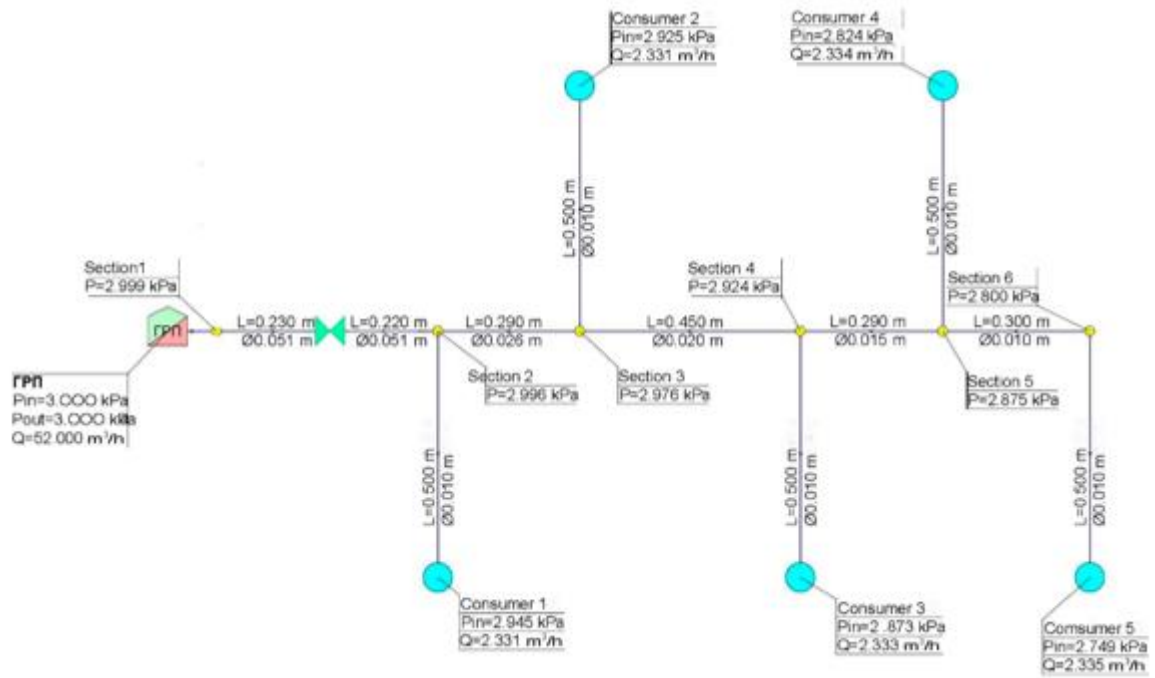

Fig. 1. *Model of the dead-end gas network*

ГРП - gas supply source; - consumer; - the valve is "open"; - the valve is "blocked"

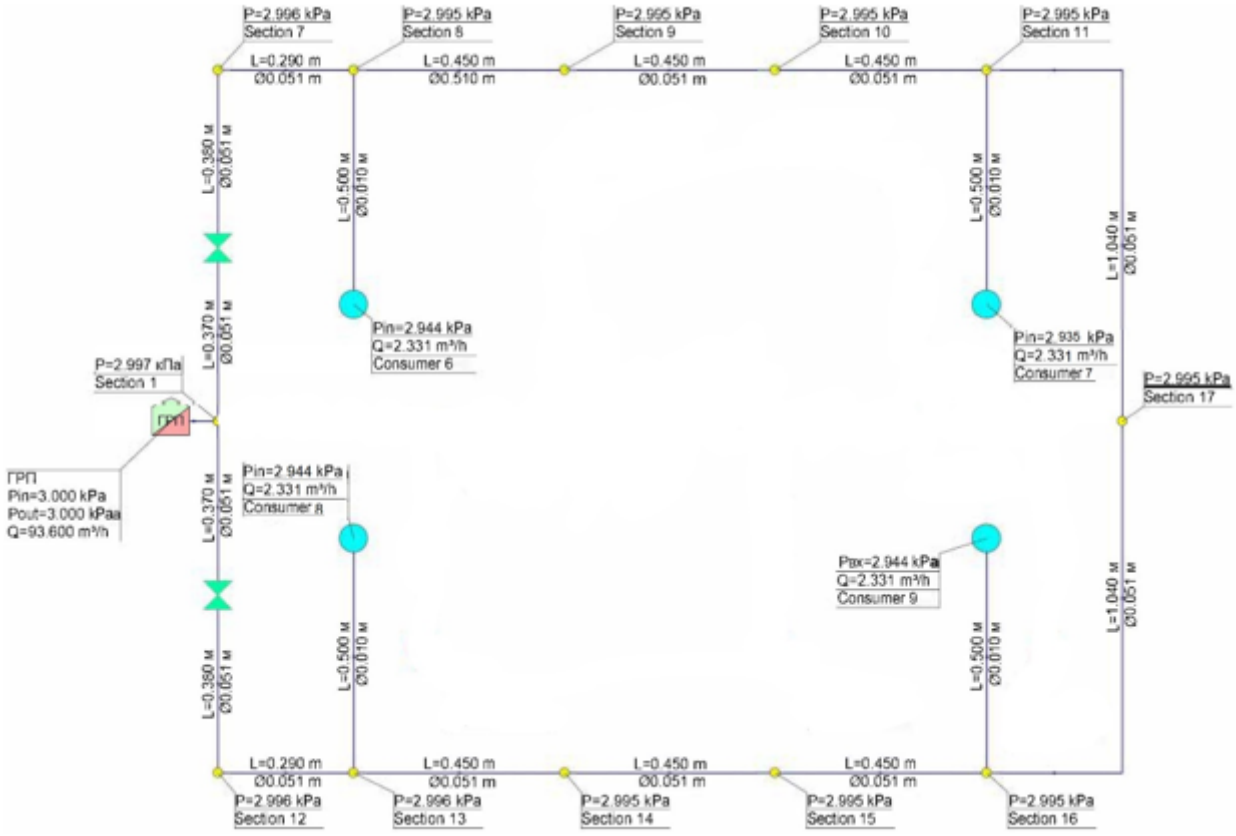

Fig. 2. Model of the ring gas network

ГРП - gas supply source; - consumer; - the valve is "open"; - the valve is "blocked"

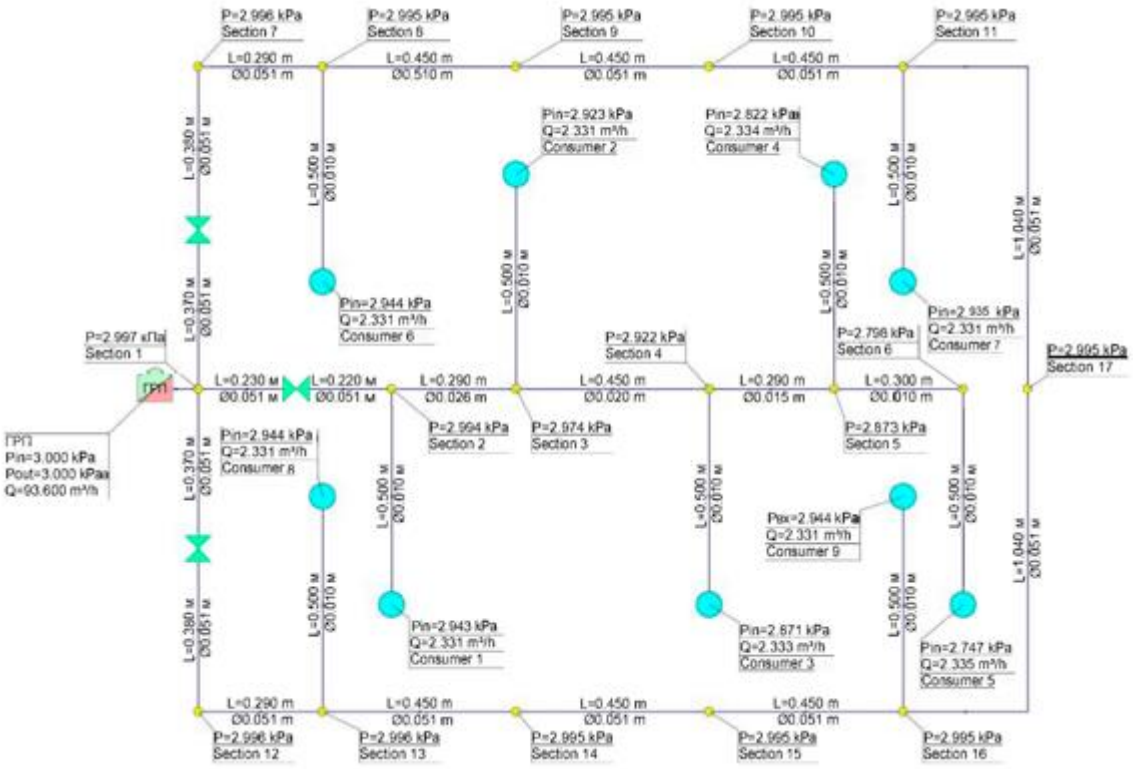

Fig. 3. Model of the mixed gas network

- gas supply source; - consumer; - the valve is "open"; - the valve is "blocked"

Results and Discussion

After completing a series of measurements at the laboratory stand and a series of calculations in ZuluGaz 10.0, piezometric graphs were constructed from the gas supply source to the most remote consumers for dead-end and ring gas networks (Figures 4, 5).

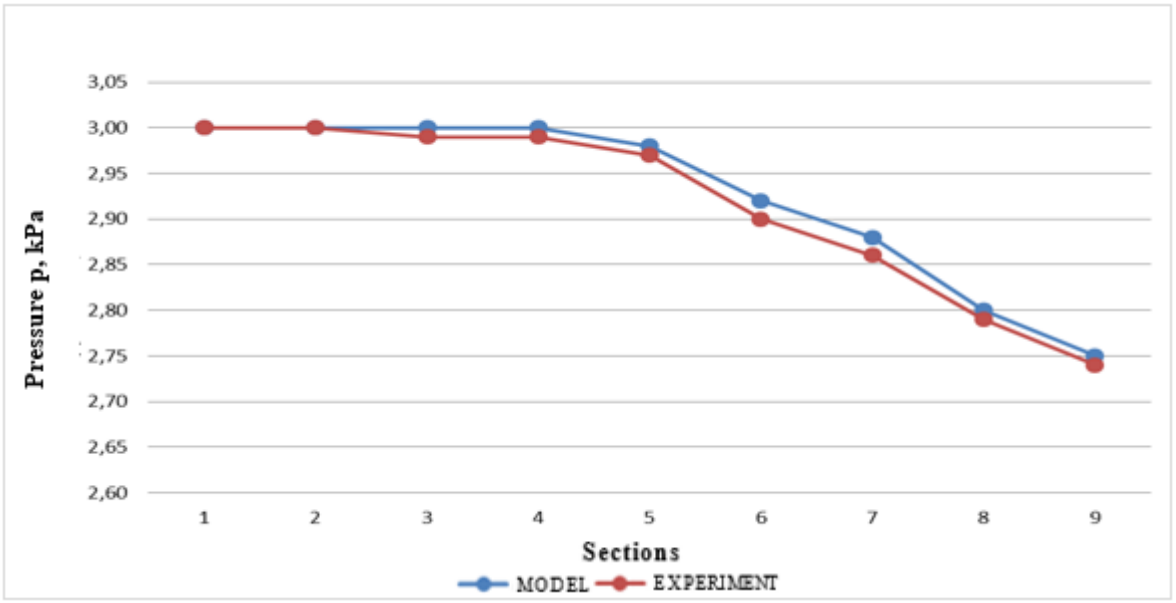

Fig. 4. *Piezometric graphs for the dead-end gas network*

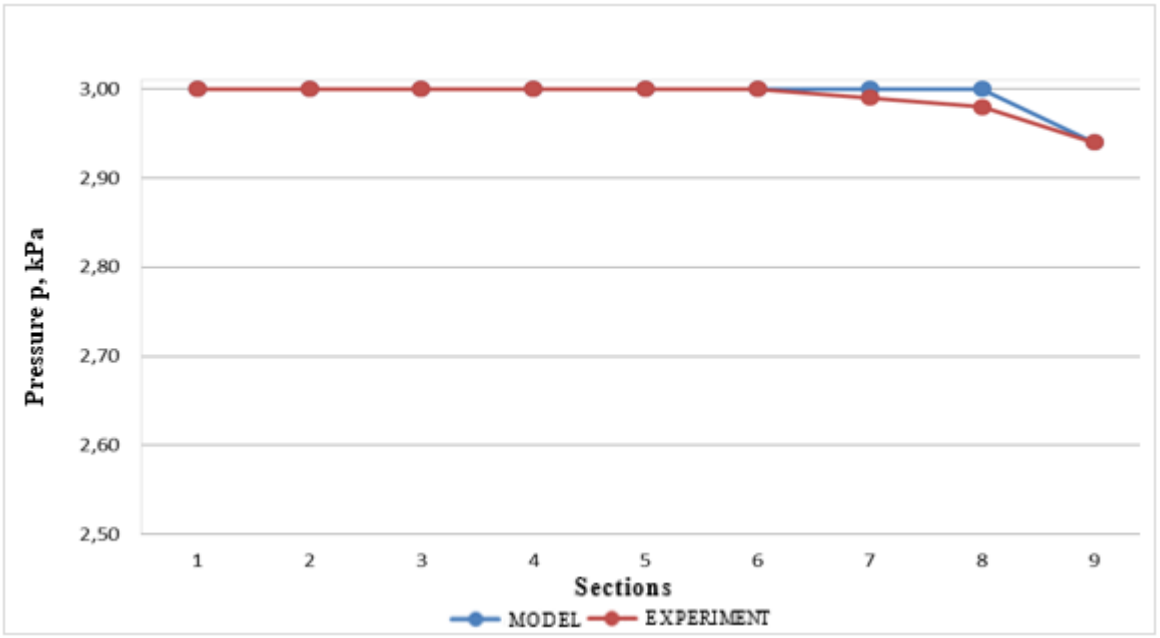

Fig. 5. *Piezometric graphs for the ring gas network*

The characteristics of the electronic model of gas networks showed almost complete identity with the results of the experiment. The results are shown on piezometric graphs (Figures 4,5).

According to the results of the study, it can be concluded that the calculation performed in ZuluGaz 10.0 creates a very accurate electronic model of the laboratory stand.

Conclusion

During the research, a comparative analysis of the electronic model of gas networks with an experiment was performed. The simulation results in ZuluGaz 10.0 almost completely coincided with the results of an experiment at the laboratory stand. Based on this, we can conclude about the high efficiency of the use of geoinformation systems for the design of gas distribution and gas consumption systems.

However, it is worth noting that this geoinformation system does not take into account the wear of gas pipelines and gas-using equipment installed on them. The solution of this problem can be the basis for further research.

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Received: 17.05.2022
Revised: 24.05.2022
Accepted: 25.05.2022

DOI: https://doi.org/10.54338/27382656-2022.2-003

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METHOD OF CALCULATION OF THE SEDIMENT DRYING STRUCTURE IN NATURAL CONDITIONS

Dewatering of sediments of natural water treatment plants is one of the most important technological and environmental problems of their operation. The use of drying in natural conditions ensures low energy consumption with the achievement of the necessary results in the moisture content of the sediment. The increase in the rate of dehydration is facilitated by the use of structures using the capillary effect to increase the rate of dehydration. The designs of dewatering sites with such elements have been developed and the article presents the method of their calculation.

Keywords: *natural water purification, sediment, capillary effect, dehydration.*

Introduction

Any liquid is limited by the interface surfaces separating it from any other medium - vacuum, gas, solid, other liquid. The energy of the surface molecules of the liquid is different from the energy of the molecules inside the liquid precisely due to the fact that both have different neighboring molecules - the surrounding molecules are the same for the inner molecules, the surface molecules have the same molecules located only on one side. The difference of these energies is called surface energy. The surface energy is proportional to the number of surface molecules (i.e. the area of the interface) and depends on the parameters of the media in contact. This dependence is usually characterized by a surface tension coefficient.

The use of a material with a large number of capillaries for dewatering precipitation has been known before. So back in the 70s of the twentieth century, a method for dewatering sludge was patented using a structure loaded with a filler of the hemp rope type [1]. However, the use of this device requires periodic extraction of the filler with subsequent pumping of water from the container in which it was located, which is not very convenient with a significant amount of sludge formed at large water treatment plants. The use of the capillary effect for the purpose of dewatering the sediment of stations in the south of the Russian Federation has not been studied before, therefore, the task was set to study the properties of various materials in terms of intensification of moisture removal. In this case, an important condition of the dehydration process is the spontaneous evaporation of liquid from the surface of the capillary element. In the future, we will call a capillary element a structure located in the sediment, which ensures the extraction of water from it by means of a capillary effect.

The use of the capillary effect for the purpose of dewatering the sediment of water supply stations as a method was developed by the staff of the Department of Water Supply and Sanitation of Rostov State University of Civil Engineering (now DSTU).

The essence of the method lies in the fact that the sediment of settling facilities previously compacted in thickeners (facilities for the reuse of washing water of rapid filters, sedimentation clarifiers with a layer of suspended sediment) with a humidity of 91 to 97 percent is pumped into a container in which a special material is placed along the walls that has the ability to create capillary pressure directed upwards (Fig. 1). The maximum height to which capillary water can rise through the material will be the height of the raised column of water, counting from the surface of the sediment, to the height at which the weight of the column of water per unit cross-section of the tube will be equal to the lifting force of the meniscus. In this regard, the height of the walls above the sediment level is assumed to be less than the maximum, providing overflow.

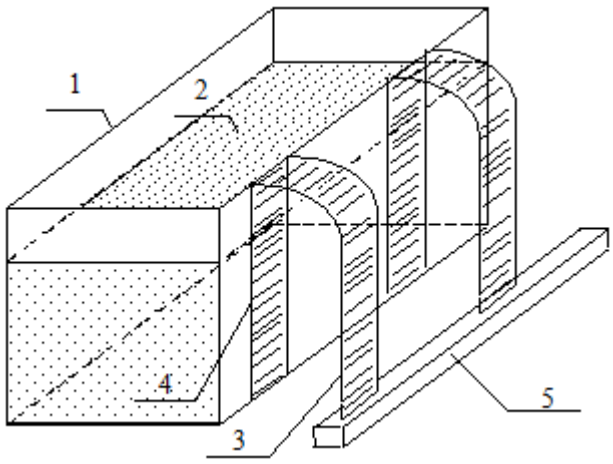

Fig. 1. *Scheme of the method of dewatering water sludge using capillary pressure.*
1 - *container,* 2 - *sediment,* 3 - *overflow,* 4 - *capillary material,* 5 - *water collection tray*

The capillary material allows water to be removed not only by lifting in the capillaries with the movement of liquid into the collecting tank, but also by forming an additional evaporation area with drying patterns different from evaporation from the liquid surface. As a result, depending on the climatic characteristics of the region (lack of humidity, wind speed), the increase in the rate of dehydration can reach 2-3 times with a final humidity of 75 to 60%.

A number of structures have been developed using capillary elements [2,3,4,5], including a closed-type tank structure for sludge dewatering [5] (Fig. 2).

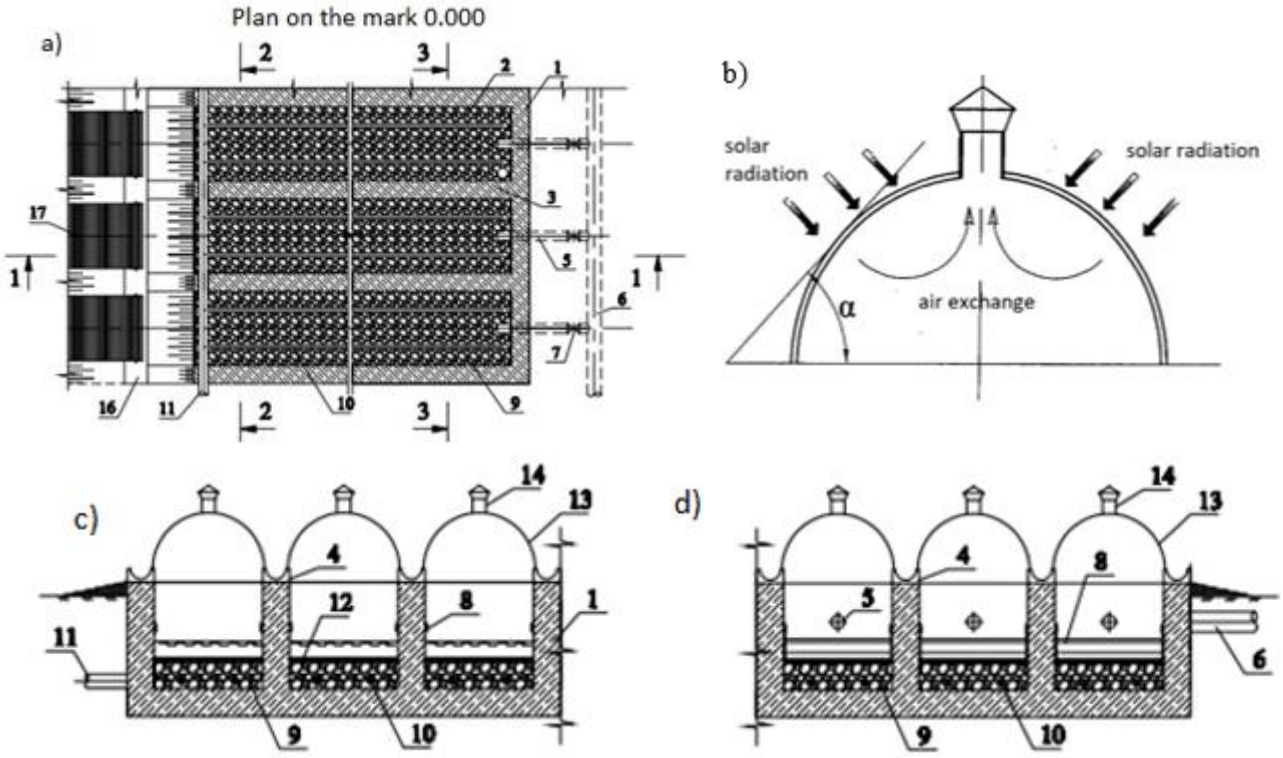

Fig. 2. *A closed-type tank structure for dewatering sediment*
a) longitudinal section, b) roof scheme, c) transverse section through the filtrate discharge pipeline, d) transverse section through the sediment supply pipeline. 1 - reinforced concrete tank, 2 - working corridor, 3 - reinforced concrete walls, 4 - concrete condensate collection trays, 5 - inlet pipeline, 6 - sludge supply pipeline, 7 - cold - free valve, 8 - scraper mechanism, 9 - gravel drainage, 10 - drainage pipes, 11 - filtrate drainage pipeline, 12 - drainage plates, 13 – roofing, 14 - deflector

The structure is a reinforced concrete tank with enclosing walls dividing it into independently operating corridors, which are equipped with drainage and a scraper mechanism, as well as a slurry water supply pipeline, inlet and drainage pipelines, and a dedicated filtrate discharge pipeline. The main difference between a closed-type structure is the presence of a coating of a special design - a roofing with deflectors installed in it, and a concrete tray is laid along the top of the enclosing walls. The roofing is made of a light–permeable material, which not only effectively protects the sediment from rain and snow, but also contributes to maximum radiation absorption when it is oriented in the west - east direction. The optimal angle of inclination of the roof (α) is recommended to be taken equal to the geographical latitude of the terrain. The sun's rays, passing through the roofing, heat the air inside the corridor and create a favorable microclimate for the evaporation of moisture, and deflectors contribute to the activation of convection currents, along with which water vapor escapes into the atmosphere. For the removal of thawed and rainwater along the upper edge of the reinforced concrete walls, the device of concrete trays with the removal of water into the industrial sewer is provided.

Reinforced concrete walls, in addition to the enclosing function, act as a capillary-porous material for the capillary lifting of moisture and its further evaporation from the concrete surface. The construction of reinforced concrete walls is made according to the "sandwich" principle - the bearing part of the wall made of heavy concrete and the capillary material between which the waterproofing layer is arranged (Fig. 3). Such a wall design allows you to simultaneously ensure the strength of the structure and the possibility of replacing the capillary material in case of its clogging.

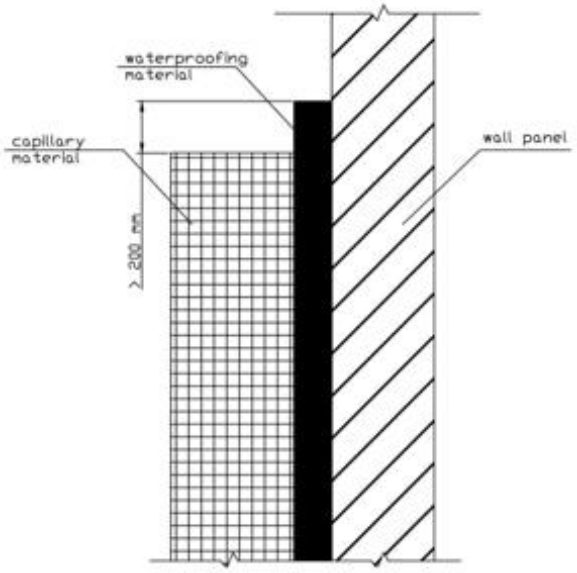

Fig. 3. *The version of the wall of the "sandwich" capacitive structure*

The introduction of structures into practice required the development of a methodology for calculating the structure.

Materials and Methods

According to the classification of materials undergoing drying proposed by academician A.V. Lykov [6], the sediment refers to colloidal capillary-porous materials (earlier, Turovsky I.S. came to the same conclusion regarding the sediment of sewage stations [7]). It is impossible to remove all moisture from the sediment during drying in its natural state - exposure to air and solar radiation, because the drying process can only be brought to an equilibrium moisture content and the corresponding humidity. In this case, the concept of the removed moisture content is used - the difference between the moisture content and the equilibrium moisture content, depending on the humidity of the air.

The dynamics of sludge drying (both water and sewer) according to the works of V.M. Lyubarsky [8] and I.S. Turovsky [7] includes periods of sludge heating, a period of stable drying speed and falling drying speed,

at the boundary of which it is customary to allocate the first critical point – the point of change in the slope of the drying curve. V.M. Lyubarsky leads to the results of drying precipitation with a different ratio of turbidity and chromaticity. Precipitation formed during the clarification of water with turbidity exceeding chromaticity, during drying in the region of constant velocity (constant temperature of the sediment), free and physicomechanically bound moisture is released from itself, reaching a humidity of up to 64% (the first critical point). In relation to dewatering sites in natural conditions, the author considers and takes into account two drying areas: heating of the sludge to the temperature of a wet thermometer and drying at a constant speed (constant temperature of the sludge). The proposed scheme of dewatering using capillary elements makes it possible to speed up the drying process by extracting water from the thickness of the sediment layer. The contact of the sediment with the capillary element, in which the lower moisture content in the element in comparison with the sediment creates a moisture content gradient at the sediment-element boundary. Thus, moisture from the sediment passes into the element and due to capillary rise through open pores, an additional evaporation area is formed in it.

It is possible to determine the time of sludge dewatering by filtration either using the equation of Prof. N.N. Verigin derived for sewage sludge, or by transforming the formula for determining resistance [10].

Filtering time by N.N. Verigin:

$$t = \frac{100H}{\mathrm{K}}\left\{\left[1 + aa_1\left(\frac{\delta_s}{H} + 1\right)\right] ln\frac{\delta_s + H}{a_2\delta_s + H} - aa_1\frac{\delta_s}{H}(1 - a_2)\right\}, \text{day}, \quad (1)$$

where H – the thickness of the filter layer, m, should be taken equal to the thickness of the sediment at the end of the second phase of compaction without mechanical mixing of the sediment,

δ_s – initial thickness of the unconsolidated sediment layer, m,

$a = \frac{\mathrm{C}}{\rho_v}$, C – concentration of the solid phase in the unconsolidated sediment, kg/m^3:

$$\mathrm{C} = \frac{\rho_l\rho_s(1 - W_s)}{\rho_l + (\rho_s - \rho_l)W_s}\ , \quad (2)$$

where ρ_l and ρ_s – accordingly, the density of water and solid sediment, kg/m^3,

W_s – humidity of unconsolidated sediment – sediment entering the sealer, fractions of a unit,

ρ_v – the density of the bulk mass of the skeleton of the compacted sediment:

$$\rho_v = \frac{\rho_l\rho_s(1 - W_{\text{h.s.}})}{\rho_l + (\rho_s + \rho_l)W_{h.s.}}, \quad (3)$$

where $W_{\text{h.s.}}$ – humidity of the sediment in the sealer after the end of the second phase of the seal, fractions of a unit: $W_{\text{h.s.}} = \frac{W_s - \frac{H}{\delta_s}}{\left(1 - \frac{H}{\delta_s}\right)}$,

$a_1 = \frac{K}{K_{\text{h.s.}}}$ (K - drainage filtration coefficient, $K_{\text{h.s.}}$ - filtration coefficient of compacted sediment, m/s),

$a_2 = \frac{a}{1+a}$ – dimensionless parameters.

Based on the formula for determining the filtration resistivity (at a liquid temperature 10°C)

$$t = \frac{r \cdot V^2 \cdot C \cdot \eta}{2pF^2} = \frac{r \cdot h^2 \cdot C \cdot 1{,}3 \cdot 10^{-3}}{2 \cdot h_r \cdot 10000} = 7.52 \cdot r \cdot h^2 \cdot C \cdot 10^{-12}/h_g, day\ , \quad (4)$$

where h_g - geodesic difference of the mark of the top of the compacted sediment and the center of the drainage pipeline drainage water from the site, m.

The value of the monthly evaporation layer E_m

$$E_{\text{m}} = 0.15 \cdot \mathrm{T}(l_0 - l_{200})(1 + 0.72V_{200})\ , \quad (5)$$

where T is the number of days per month during which sediment dehydration occurs, day,

l_0 is the elasticity of saturated water vapor corresponding to the average air temperature for the month, mb,

l_{200} – average monthly absolute humidity at a height of 200 cm from the water surface, mb, equal to

$$l_{200} = l_1 + M(l_{\text{lim}} - l_1)\,, \tag{6}$$

where l_1 – absolute humidity of air over land for a given month, mb,

l_{lim} – the maximum humidity of the air with an unlimited stay of the air flow over the reservoir, approximately can be assumed equal to 0.8 l_0,

M – empirical coefficient depending on the duration of the air flow over the reservoir.

The volume of water removed from the surface during evaporation from the surface of the capillary material

$$V_{\text{k.s.}} = F_{k.s.} \cdot \sum \text{E}'_{\text{m}}\,, \tag{7}$$

where $F_{k.s.}$ – the area of capillary rise for all capillary materials above the water level in the site, m^2,

E'_m – the value of the monthly evaporation layer from the surface of the capillary material located above the water level, mm.

The height of elevation in the capillary material is taken according to the formula of Juren:

$$h = \frac{2 \cdot \sigma}{\rho \cdot g \cdot r_0}\,, \tag{8}$$

where r – drop radius, m,

σ - surface tension, H/m,

ρ - water density, kg/m^3.

Results and Discussion

The calculation of the dewatering site with capillary elements is based on a known ratio for the rate of moisture loss with the introduction of an additional term for the evaporation of moisture from the capillary material:

$$Q = \frac{dV}{dt} = \frac{dV_{dr}}{dt} + \frac{dV_{k.s.}}{dt} + \frac{dV_f}{dt} + \frac{dV_d}{dt}\,, \tag{9}$$

where V – total water content in the sediment,

V_{dr} – the volume of water removed from the sediment surface as a result of drying,

$V_{k.s.}$ – volume of water evaporating during drying of capillary material,

V_f – the volume of water removed during filtration into the drainage system,

V_d – volume of water removed by decantation.

Based on this, it is fair to say that the total volume of water removed from the sediment will be equal to the sum of the volumes of water removed by drying, filtering through the drainage system and from the surface of the sediment after its decantation. If the design of the site does not provide for the possibility of removing decanted water, then V_d should be taken equal to zero.

Volume of water removed from sediment:

$$\Delta V = V_b - V_{end}\,, \tag{10}$$

where V_b – the volume of water in the sediment corresponding to the humidity of the sediment entering the site,

V_{end} – the volume of water in the sediment corresponding to the calculated moisture content of the sediment or the moisture content of the sediment removed from the site.

Based on the determination of humidity and taking the humidity of the sediment after the sealer at least 95%, it is possible to determine the volume of water removed in the sediment compactor (sealer-averager) or at the site of natural dehydration:

$$\Delta V = V_b \left(\frac{W_b - W_{tnd}}{100 - W_{end}}\right), \quad (11)$$

where W_b and W_{end} – accordingly, the humidity of the sediment entering the drying area and removed from it, %.

We determine the volume of sediment formed in sedimentation tanks per month with the maximum content of suspended solids in the water source, the volume of sediment in the facilities of repeated use of flushing for the same period. We calculate the volume of the mixture with a humidity of 91-93% after the sedimentation compactor (sealer-averager) W_s.

The area of the sludge dewatering facility (F, m^2) is proposed to be calculated using the formula:

$$F = \frac{W_s}{h}, \quad (12)$$

where h – the height of the sediment inlet layer to the site, m, accepted 0.4÷0.6 m.

Being structurally determined by the thickness of the capillary element $b_{c.e.}$ (no more than 200 mm), we determine the width of the corridor "in the light":

$$B_к = 2 \cdot 5 b_{c.e.}. \quad (13)$$

Number of working corridors:

$$N_w = \frac{F}{B_c L_c}, \quad (14)$$

where $L_к$ – the length of the corridor, m, is accepted no more than 40 m.

The number of working corridors should be taken at least two.

The construction height of the structure can be calculated using the formula:

$$h_{bul} = \sum h_{seal} + h_{dr} + h_{scr.} + h_{pip.} + 0.5, \quad (15)$$

where h_{dr} – drainage height, m, representing the sum of the outer diameter of the drainage pipe, the thickness of the drainage backfill layer (at least 10 cm), the thickness of the drainage plates,

$h_{scr.}$ – vertical size of the scraper mechanism, m,

$h_{pip.}$ – the outer diameter of the intake pipeline, m.

The formula (11) calculates the amount of water removed from the sediment when the humidity changes from 91-93 to 60% per month with the maximum content of suspended solids.

The volume of water to be decanted and (or) filtered is defined as the difference between the height of the sediment inlet layer (h) and the thickness of the sediment at the end of the second phase of compaction on the area of the structure (you can take 0.4-0.45 h). The filtering time is calculated by formulas (1) and (4), taking a smaller value.

Based on the value of the filtration time and the volume of water to be filtered, the volume of water discharged by the drainage system per month is calculated.

For each of the months of the year, the amount of water evaporated from the surface and from capillary elements is calculated (formulas 5-8). For example, in the following tabular form:

Month	Average monthly temperature, T, °C	Average elasticity of saturated water vapor l_0, mb	Absolute humidity of air over land, l_1, mb	Average elasticity of water vapor l_{200}, mb	Wind speed , V_{ref}, m/s	Wind speed at a height of 200 cm, V_{200}, m/s	Volume removed per month from the surface, m^3	Volume removed per month from capillary elements, m^3
January								
….								

The calculation of the dehydration time at the sites is performed according to the least (summer precipitation, dehydration November-March) and the most (winter precipitation, dehydration April-October) favorable periods. When calculating, you should take:

a) drainage filtration coefficients:
- drainage layer of porous concrete (expanded clay concrete) – 0.004÷0.0058 m/s,
- the drainage layer of gravel is 0.0012÷0.023 m/s.

b) sediment filtration coefficient (at a water temperature of 10°C):

$$K_{\text{h.s.}} = \frac{1{,}54 \cdot 10^{10}}{rC}\,. \tag{16}$$

c) the empirical coefficient "M":
- for open areas is determined based on V_{200}, the location of the site on the cardinal directions, the wind rose in the area of construction of the site, and the size of the site in the prevailing direction of winds,
- for closed sites, it is accepted within 0.2÷0.3,

d) V_{200} – average wind speed at a height of 200 cm, m/s:

$$V_{200} = 0.8K \cdot V_{ref}\,, \tag{17}$$

where V_{ref} – wind speed, m/s,
K – is a coefficient depending on the local conditions of the location of the meteorological station, taking values (Table III-10[9]):
- forest areas of the Russian Federation – 1.6÷3.0,
- treeless areas of the Russian Federation – 1.3÷1.9,
- shores of sea bays, lakes and large rivers – 1.05÷1.6.

e) the radius of the capillary (capillary pore) is taken according to reference materials based on the type of material, for example:
- heavy concrete 0.01 – 1 microns,
- ceramic brick – 0.1 – 20 microns.

Considering that the pore radius is represented as an interval for each material, we consider it correct to calculate for the maximum radius and introducing a reduction factor of 0.5. This creates a certain margin in the amount of evaporated water from the capillary element.

f) capillary rise area

$$F_{k.s.} = P_{k.s.} \cdot h_{k.s.min}\,. \tag{18}$$

The annual amount of sediment is determined after the compactor-averagers (sedimenters), based on the average annual content of suspended solids. The possibility of dehydration in the remaining months of the volume of sediment not dehydrated in the previously calculated periods is checked.

If the sum of the dehydration time does not exceed one year, then the number of working corridors calculated according to formula (14) is left unchanged. If the amount exceeds one year, then the number of corridors should be increased.

Conclusion

The capillary effect during the dewatering of natural water sediments makes it possible to intensify the process of drying the sediment in natural conditions up to a humidity of 60%. The method of sediment dewatering in natural conditions using the capillary effect, as well as the dewatering site has been developed and patented. The method of calculating sites is based on the radiation-convective form of drying of the capillary element, evaporation from the liquid surface, filtration into the drainage system allows the calculation of structures located in places with a constant or prevailing humidity deficit throughout the year.

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Received: 17.05.2022
Revised: 10.06.2022
Accepted: 15.06.2022

DOI: https://doi.org/10.54338/27382656-2022.2-004

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PROBLEMS RELATED TO CREATION OF ESTIMATE AND ORGANIZATIONAL -TECHNOLOGICAL DESIGN DATABASES IN BIM

The problems related to formating of estimate and organizational-technological design simplified databases in BIM platform are considered (explored). It is proposed to combine the data necessary for estimate and organizational-technological design in one flexible system with an option of updating the information in its sub-systems by monitoring the means suggested.

Simplified formulas for calculation of costs are presented which allows us to come to certain conclusions regarding the approaches to determination of operational expenses for various construction machines and mechanisms.

Keywords: construction, machines, mechanisms, database, BIM, design, estimated cost.

Introduction

Problems of various nature arise at the spatial and geographic enlargement of design in BIM environment both in the developed and developing countries.

If the problems of 3D modeling of objects are related to the development of appropriate software, regulatory standards or the adoption of international standards, then 4D and 5D modeling requires creation of large databases, and they have many functions depending on the nature of national pricing system, local prices of materials and structures, named machines and mechanisms, etc.[1].

The key problem of automation of the estimate and organizational-technological design is associated with the following fact: design programs for architectural and engineering systems enable determining the cost of construction and materials when setting of the scope of works is a more difficult task and requires use of additional methods, often with application of "artificial intelligence" in order to choose the proper work from existing works database and to determine labor intensity or its estimated cost.

The creation of automated or, more precisely, semi-automated organizational-technological and estimate design systems in RA supposes creation of updated resource bases and adoption of resource method for determination of the construction estimate cost in construction sector, which is carried out by state funds. In private sector the calculations are made by resource method but often they are approximate and subjective.

Creation of database is useful for both sectors as determination of precise costs cannot be an obstacle for any private organization to plan its profit margin when in case of wrong calculations significant contingency expenditures may arise [2,3].

Having examined international experience, we have concluded that the "rich" countries can afford an approximate calculation - additional investment in case of unforeseen increase in costs, but in those countries making accurate calculations to plan the work and assess the risks is preferred as well [4,5,6].

Steps for pricing conceptual modernization are being undertaken in RA but they are still on stage of programming while technology develops so fast.

We think it is a task of specialists to offer electronic versions of estimate and organizational-technological design and selection of more effective one from them in order to include in common design system.

In particular, we offer the structure and content of an estimate-normative information database of construction machines, mechanisms, tools, and equipment.

Materials and Methods

We reviewed the structures and compositions of the project regulatory databases of the post-soviet republics (Russian Federation, Ukraine, Belarus, Kazakhstan), Italy, France and other developed countries. On the basis of a comparative analysis, a reform concept was developed based on international best practices, the features of the RA construction industry, the cryptographic efficiency of 4D and 5D modeling database elements in the BIM platform.

Research

The traditional structure of estimate-normative base is shown in Fig. 1. The data of all blocks needs updating but first of all the resource base must be updated and the update of one of its components ("Database of machines and mechanisms) is the main goal of this research.

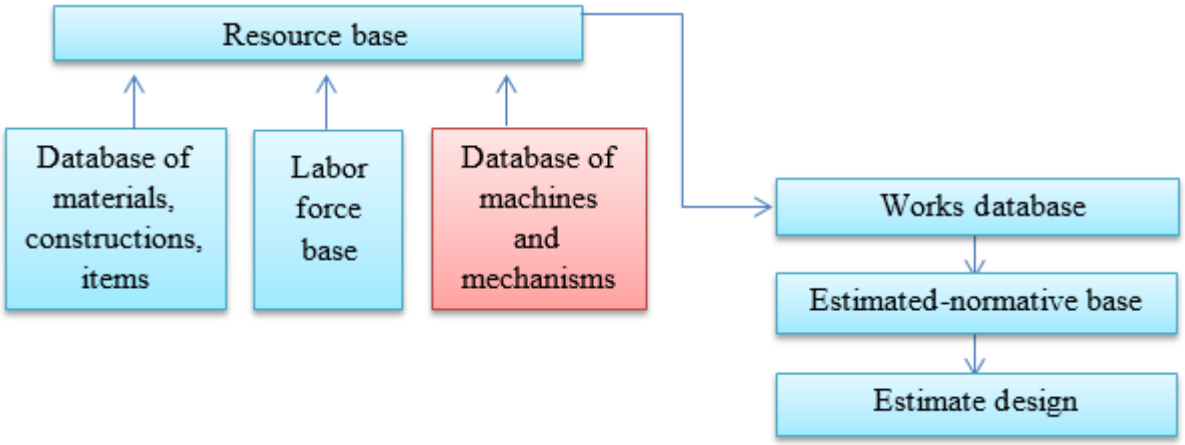

Fig. 1. *Structure of the estimate-normative base*

It is suggested to combine the estimate and organizational-technological normative bases (Fig. 2) by means of presentation of additional data in the updating database.

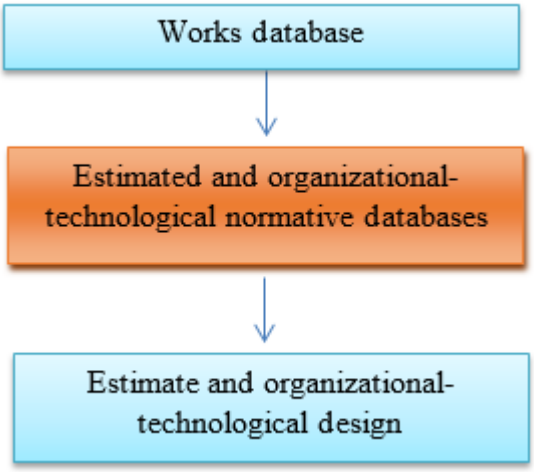

Fig. 2. *Scheme of combined estimate and organization-technological normative bases*

The electronic databases shall be as simple and attractive for use as possible, enabling automatically update of information.

The database consists of 3 sub-systems:

- master system which includes the classified codes and brands of machines, mechanisms and equipment, as well as the cost of one machine/hour (Table 1),
- technical parameters (Table 2),
- calculator of 1 machine/hour cost (Table 3).

Table 1. Master system

INFORMATION DATABASE OF ESTIMATE-NORMATIVES OF CONSTRUCTION MACHINERY, MECHANISMS, TOOLS, EQUIPMENT						
Magnified group code	**Magnified subgroup code**	**Brand code**	**Type code**	**Name**	**Brand**	**Cost of 1 machine/hour**
Types of construction equipment						
	Wheeled excavators					
01	001	001	001	Caterpillar (Cat)	M316D	
01	001	001	002	JCB	JS175W	
01	001	001	003	Komatsu	PW200-7	
	Crawler excavators					
01	001	002	001	Caterpillar (Cat)	324DL	
01	001	002	002	JCB	JS260	13948.48
01	001	002	003	Komatsu	PC300-7	
	Excavators - loaders					
01	001	003	001	Caterpillar (Cat)	428E	
01	001	003	002	JCB	4CX	
01	001	003	003	Komatsu	WB97S-5E0	

The connection between sub-systems is made by activating the links. In particular, activating the field of cost of one machine/hour the user switches to the calculation subsystem. In the calculation subsystem, the initial cost of the vehicle is transferred from the technical and value parameters subsystem, where the cost parameters are regularly updated on the basis of monitoring.

The cost of 1 machine/hour is calculated in accordance with the following logic:

The cost of operation of machines and mechanisms includes direct and indirect expenses:

$$C_{m/h} = E_d + E_{ind} + P\ , \tag{1}$$

E_{ind} – *indirect costs*: expenses that don't relate directly to the functions, products or operations of a construction project (such as costs of administrative processes and salaries for staff are indirect costs that construction companies are typically responsible for),

P – *profit,*

E_d – *direct costs.*

The direct costs in their turn consist of several components:

$$E_d = E_{dep} + E_m + E_f + E_{sm} + E_{so}\ , \tag{2}$$

E_{dep} – *depreciation costs* (the operating machines and mechanisms are subject to depreciation, the costs of acquiring machines, mechanisms and equipment are allocated by means of depreciation calculation over the periods during which their use provides certain income),

E_{sm} – *salary of maintenance personnel,*

E_{so} – *salary of operating personnel,*

E_f – *fuel expenses* (fuel expenses shall be determined on the base of certificate data of any machine of certain model),

E_m – *material costs.*

In order to simplify the calculations, the expense of materials (lubricants, repairs, maintenance parts, etc.) is determined on the basis of fuel expenses in a defined percentage, which allows updating the cost of 1 machine-hour of machine operation by monitoring the car fuel values, average wages of workers.

Table 2. Technical parameters

Code	Name	Brand	Technical parameters		
	Wheeled excavators				
01001001001	Caterpillar (Cat)	M316D	Weight	kg	17600-19800
			Bucket volume	m^3	0.4-1.3
			Engine power	kW	118
			Drilling depth	m	6.10
			Dimensions	m	8.39/2.55/3.17
01001001002	JCB	JS175W	Weight	kg	18000
			Bucket volume	m^3	0.35-0.9
			Engine power	kW	102
			Drilling depth	m	6.23
			Dimensions	m	9.1/2.5/3.01
01001001003	Komatsu	PW200-7	Weight	kg	20860
			Bucket volume	m^3	0.48-1.68
			Engine power	kW	118
			Drilling depth	m	5.40
			Dimensions	m	9.43/2.54/3.9
	Crawler excavators				
01001002001	Caterpillar (Cat)	324DL	Weight	kg	26100
			Bucket volume	m^3	0.49-1.61
			Engine power	kW	124
			Drilling depth	m	6.56
			Dimensions	m	10.6/3.39/2.98
01001002002	JCB	JS260	Weight	kg	27200
			Bucket volume	m^3	0.77-1.46
			Engine power	kW	120
			Drilling depth	m	7.23
			Dimensions	m	10.2/3.49/3.78
01001002003	Komatsu	PC300-7	Weight	kg	30800
			Bucket volume	m^3	0.52-1.4
			Engine power	kW	180
			Drilling depth	m	7.38
			Dimensions	m	11.14/3.19/3.28
	Excavators - loaders				
01001003001	Caterpillar (Cat)	428E	Weight	kg	8800
			Shovel volume	m^3	0.08-0.38
			Bucket volume	m^3	1.03
			Engine power	kW	75
			Dimensions	m	5.8/2.37/2.86
			Drilling depth/radius	m	5.3/6.64
			Unloading height	m	1.26/2.67
01001003002	JCB	4CX	Weight	kg	8660
			Shovel volume	m^3	0.04-0.48
			Bucket volume	m^3	1.10
			Engine power	kW	71.00
			Dimensions	m	5.91/2.36/3.7
			Drilling depth/radius	m	5.53/6.53
			Unloading height	m	1.17/3.21
01001003003	Komatsu	WB97S-5E0	Weight	kg	8700
			Shovel volume	m^3	0.19
			Bucket volume	m^3	1/3.9/2
			Engine power	kW	74
			Dimensions	m	5.895/2.44/3.71
			Drilling depth/radius	m	6.465/7.17
			Unloading height	m	1.21/2.84

Table 3. Calculator of the cost of 1 machine/hour

Expenditure components	Unit of measurement	Quantity	Unit cost	Total
JCB JS260				
Depreciation deductions				
Cost of the car	pc	1.000	56 180 000.000	
Depreciation deductions	hour	1.000	0.000	3612.397
Car maintenance cost				
Fuel consumption (diesel)	liter / hour	5.000	500.000	2500.000
Consumption of oils and lubricants	-	0.200	2500.000	500.000
Spare parts cost	-	0.080	28 899.177	2311.934
Builder-worker 4 category	hour	0.113	1276.550	144.250
Builder-worker 3 category	hour	0.113	1160.500	131.137
Builder-worker 2 category	hour	0.000	1055.000	0.000
Builder-worker of the 1st category	hour	0.085	949.500	80.708
Machine operating cost:				
Driver, driver - 4 categories	hour	1.000	1276.550	1276.550
Ancillary worker / builder - 1 category	hour	0.700	949.500	664.650
Total Direct Costs				**11221.625**
Overhead 13%				1458.811
Total				**12680.437**
Profit 10%				1268.044
Total				**13948.480**

At present, any system of remuneration of workers (for example, rating system) is not used in RA. Practically, differentiated approach to the specialists' remuneration is applied. For example, the high grade drivers, operators are paid 50-100% more in relation to the average salary in the field. We think, that in case we determine the estimate by input method the specialties of workers engaged in the field of construction in RA will be systemized and their qualification will be classified which allows to determine the salary of the workers engaged in maintenance and operation of machines on the basis of the coefficients defined and the average salary in the field.

Conclusion

The automation of the estimate and organizational-technological design is possible by urgent creation of resource databases, provided that those databases have to be attractive, informative, and easily updatable.

As a version an electronic database of machines, mechanisms, equipment and tools is offered which will allow obtaining data both for organization of construction process, development of works' performance designs and flow diagrams and for determination of the estimate cost for operation of machines, mechanisms, equipment and tools.

Hence, a simplified version for definition of the cost of 1 machine/hour is offered by applying average percentage ratios for calculation of value of certain components.

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Received: 18.04.2022
Revised: 06.06.2022
Accepted: 17.06.2022

DOI: https://doi.org/10.54338/27382656-2022.2-005

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THREE KINDS OF POROSITY ON FUNCTIONALLY GRADED POROUS BEAMS

In this paper, the effects of three types of porosity on bending behavior of functionally graded porous (FGP) beams are studied. The procedure of finite element method (FEM) is established and based on the simple Timoshenko beam theory. The results achieved in this paper are presented and compared with other results in the references to verify the feasibility of implementing the formula and writing the Matlab code. On the other hand, this paper can help researchers to have an overview of the bending behavior of the FGP beams.

***Keywords**: bending behavior, functionally graded porous (FGP) beam, transverse displacement, rotation, simple Timoshenko beam.*

Introduction

Nowadays, functionally graded (FG) material has become one of the smart materials and it is used in many countries. From a mixture of ceramic and metal, it provided a continuous variation of material properties from the top surface to the bottom surface of a structure. For example, some structures like nuclear tanks, spacecraft, etc. are produced based on the above material [1-3]. Due to the high applicability of FG material, many studies related to various theories have been given to comment the mechanical behavior of FG structures as [4-9]. However, porosity of the material can occur during the manufacturing process [10-12]. So, for a good knowledge of porosity effect on bending behavior of FG structures, a study related to this issue must be considered as soon as possible. There are three types of structure, like beam, plate and shell, but researchers are usually interested in beam structures because of its wide applications. Furthermore, many different beam theories were used to analyze beam structures, like simple beam theory [13], classical beam theory [14, 15], first-order shear deformation theory [16-20] or higher-order shear deformation theory [21, 22]. However, using a simple Timoshenko beam model helps us to reduce the computational cost with the resulting error within the allowable range. On the other hand, beams made of FGP materials should be investigated as much as possible to help the designer have the right knowledge about the mechanical properties. The few published papers on static bending behavior of FG beams can be listed here. Author Chen and co-workers presented the Ritz method to obtain the transverse bending deflections and critical buckling loads, where the trial functions take the form of simple algebraic polynomials [23]. A novel model was introduced for bending of FGP cantilever beams by [24] related to shape memory alloy/poroelastic composite material. In this article, the authors verified the accuracy of the bending model by a three-dimensional (3D) finite element method (FEM). Another paper based on trigonometric shear deformation theory was used to analyze the bending, vibration and buckling characteristics of FGP graphene-reinforced nanocomposite curved beams from [25], and so on. From above reasons, this paper is given to investigate the bending behavior of FGP beams.

This paper has four parts. Part 1 gives the introduction as above. Part 2 presents the formulations as well as Part 3 shows some essential results. Finally, a few comments are also given in Part 4, respectively.

Formulations

A FGP beam with length L, width b and thickness h is considered. Three forms of porosity distributions are studied and shown in Figures 1 and 2, in which (*1*) is uniform porous distribution and (*2*) and (*3*) are non-uniform porous distributions respectively. The normalized Young's modulus $E(z)/E_1$ is depicted in Fig. 2 (a) - (c) to clarify the influences of these three forms of porosity with the value of Young's modulus at top surface, E_1.

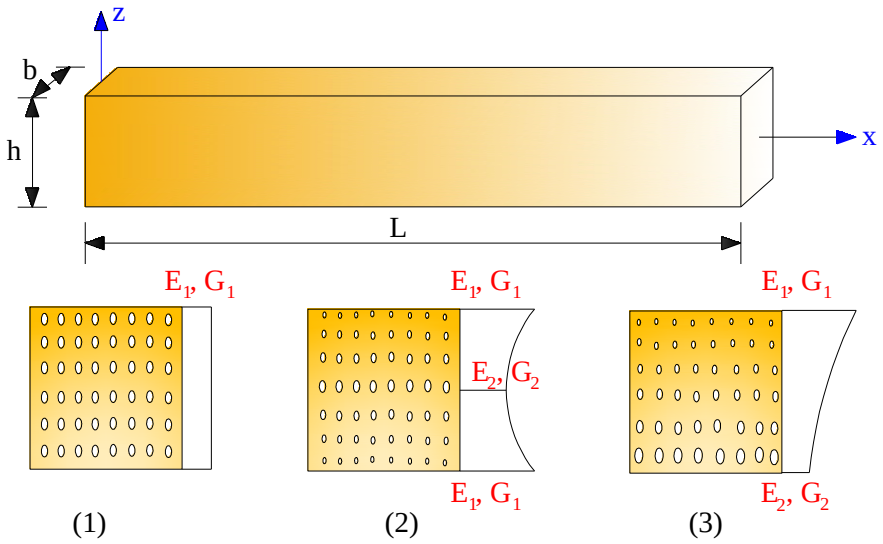

Fig. 1. *FGP beam with three types of porosity 1, 2 and 3*

The material properties such as Young's modulus, *E(z)*, and shear modulus, *G(z)*, can be described as below:

$$\begin{cases} E(z) = E_1(1 - e_0\chi) \\ G(z) = G_1(1 - e_0\chi) \end{cases} \quad \text{with} \quad \chi = \frac{1}{e_0} - \frac{1}{e_0}\left(\frac{2}{\pi}\sqrt{1-e_0} - \frac{2}{\pi} + 1\right)^2 \quad \text{for type (1)} \tag{1}$$

$$\begin{cases} E(z) = E_1\left(1 - e_0 \cos\left(\frac{\pi z}{h}\right)\right) \\ G(z) = G_1\left(1 - e_0 \cos\left(\frac{\pi z}{h}\right)\right) \end{cases} \quad \text{for type (2)} \tag{2}$$

$$\begin{cases} E(z) = E_1\left(1 - e_0 \cos\left(\frac{\pi z}{2h} + \frac{\pi}{4}\right)\right) \\ G(z) = G_1\left(1 - e_0 \cos\left(\frac{\pi z}{2h} + \frac{\pi}{4}\right)\right) \end{cases} \quad \text{for type (3)} \tag{3}$$

The porosity coefficient e_0 must satisfy $0 < e_0 < 1$ and

$$e_0 = 1 - \frac{E_2}{E_1} = 1 - \frac{G_2}{G_1}. \tag{4}$$

Based on FEM, the degrees of freedom associated with a node of a simple Timoshenko beam element are a transverse displacement and a rotation as depicted in Fig. 3. Using the principles of simple beam theory, the beam element stiffness matrix $\mathbf{K}_{el}$ will be derived

$$\mathbf{K}_{el} = \frac{E_{el}I_{el}}{L_{el}^3}\begin{bmatrix} 12/(1+\Xi) & 6L_{el}/(1+\Xi) & -12/(1+\Xi) & 6L_{el}/(1+\Xi) \\ 6L_{el}/(1+\Xi) & (4+\Xi)L_{el}^2/(1+\Xi) & -6L_{el}/(1+\Xi) & (2-\Xi)L_{el}^2/(1+\Xi) \\ -12/(1+\Xi) & -6L_{el}/(1+\Xi) & 12/(1+\Xi) & -6L_{el}/(1+\Xi) \\ 6L_{el}/(1+\Xi) & (2-\Xi)L_{el}^2/(1+\Xi) & -6L_{el}/(1+\Xi) & (4+\Xi)L_{el}^2/(1+\Xi) \end{bmatrix} \tag{5}$$

with

$$\Xi = \left(12E_{el}I_{el}\right)/\left(G_{el}sA_{el}L_{el}^2\right), \tag{6}$$

s =5/6 is called the shear correct factor; E_{el}, G_{el} and I_{el} are Young's modulus, shear modulus and second moment of area of element based on *E(z)*, *G(z)*, *b* and *h*; L_{el} is length of element and A_{el} is called the area of cross section.

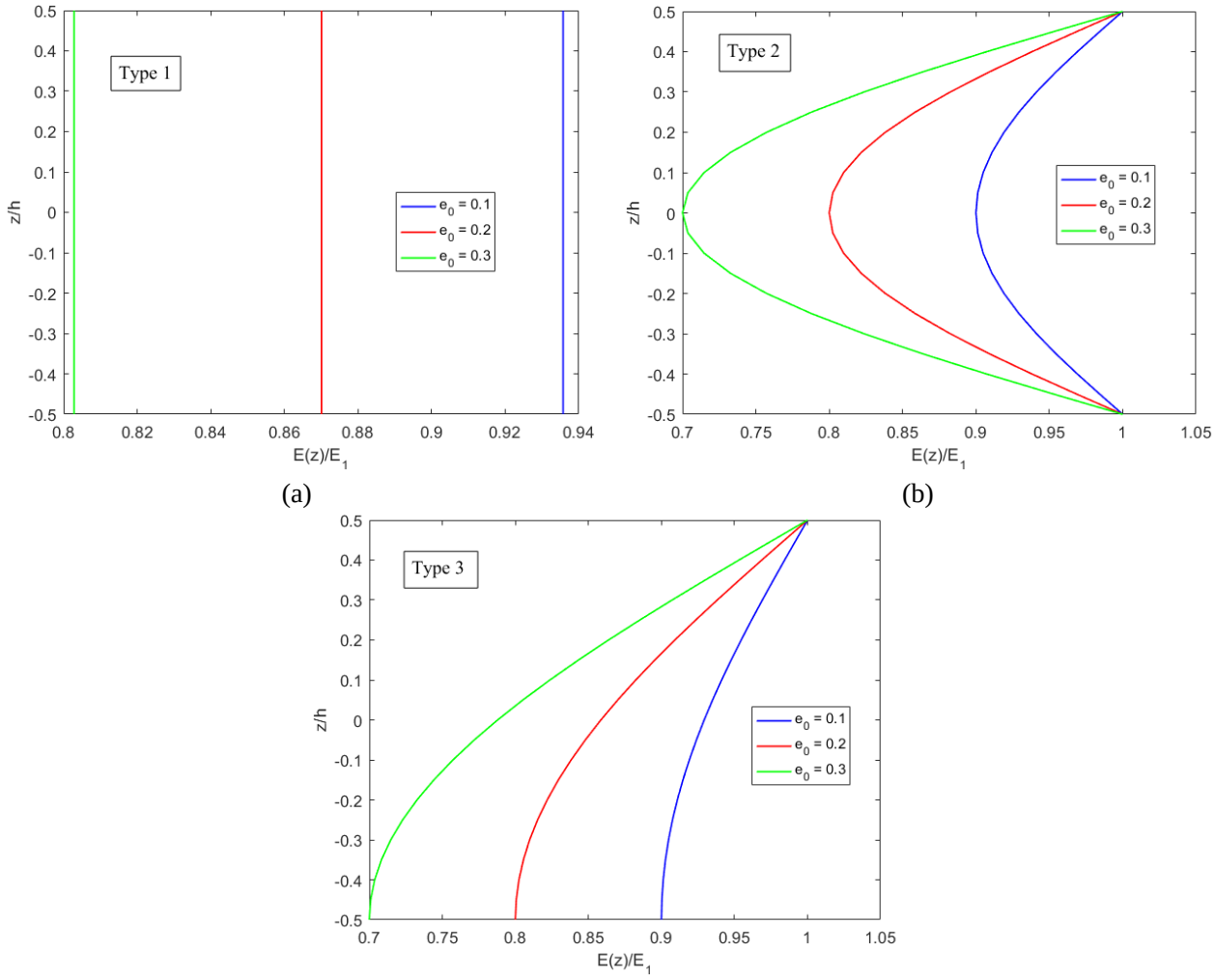

Fig. 2. *Normalized material property E(z)/E₁ with (a) type 1, (b) type 2 and (c) type 3 of porosity*

According to the principle of minimum total potential energy, the element equation can be described as

$$\frac{E_{el}I_{el}}{L_{el}^3}\begin{bmatrix} 12/(1+\Xi) & 6L_{el}/(1+\Xi) & -12/(1+\Xi) & 6L_{el}/(1+\Xi) \\ 6L_{el}/(1+\Xi) & (4+\Xi)L_{el}^2/(1+\Xi) & -6L_{el}/(1+\Xi) & (2-\Xi)L_{el}^2/(1+\Xi) \\ -12/(1+\Xi) & -6L_{el}/(1+\Xi) & 12/(1+\Xi) & -6L_{el}/(1+\Xi) \\ 6L_{el}/(1+\Xi) & (2-\Xi)L_{el}^2/(1+\Xi) & -6L_{el}/(1+\Xi) & (4+\Xi)L_{el}^2/(1+\Xi) \end{bmatrix}\begin{Bmatrix} w_i \\ \varphi_i \\ w_j \\ \varphi_j \end{Bmatrix} = \begin{Bmatrix} f_i \\ m_i \\ f_j \\ m_j \end{Bmatrix} \quad (7)$$

After assembly, the bending variables can be obtained by solving the following equation:

$$\mathbf{K}_{total}\,\mathbf{d}_{total} = \mathbf{F}_{total} \quad (8)$$

Fig. 3. *Two nodes* ***i*** *and* ***j*** *of a beam element*

By using three letters **C**, **S** and **F** refer to the clamped, simply supported and free condition, all boundary conditions can be revealed as below (Fig.4).

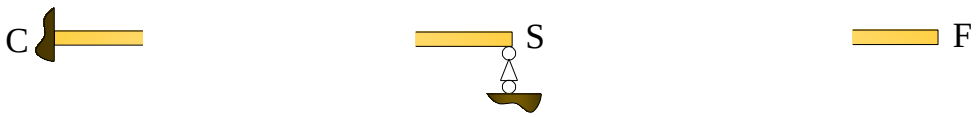

Fig. 4. *Three types of boundary condition*

From Fig. 4, the boundary conditions of system can be presented:

$$w(0)=\varphi(0)=0\ ,\ w(L)=0 \qquad \text{for CS} \tag{9}$$

$$w(0)=\varphi(0)=0\ ,\ w(L)=\varphi(L)=0 \qquad \text{for CC} \tag{10}$$

$$w(0)=\varphi(0)=0 \qquad \text{for CF} \tag{11}$$

More clearly, the finite element system of equations can be reached as below

Input data: material and geometrical properties,

Calculating constitutive matrix,

Loop over elements: calculating element stiffness matrix $\mathbf{K}_{el}$ and element force vector $\mathbf{F}_{el}$,

Assembling all parts in the global coordinate system to have $\mathbf{K}_{total}$ and $\mathbf{F}_{total}$,

Applying boundary conditions CS, CC or CF,

Solving equation to achieve $\mathbf{d}_{total}$,

Display transverse displacements w and rotations φ at nodes of system.

Numerical Examples

Firstly, the validity of the proposed model is checked for (CC) and (CS) isotropic beams under a uniform load $q = 10^6$ N/m^2. The material and geometric properties are E = 1 GPa, v = 1/3, b = 0.1 m, h = 0.1 m and $L = 10h$. The maximum transverse displacement and rotation as in the Table below are calculated and compared with analytical solutions [26] as follows:

(CC)

$$w=\frac{1}{EI}\left[\frac{1}{24}qL^2x^2-\frac{1}{12}qLx^3+\frac{1}{24}qx^4\right] \tag{12}$$

$$\varphi=\frac{1}{EI}\left[\frac{1}{12}qL^2x-\frac{1}{4}qLx^2+\frac{1}{6}qx^3\right] \tag{13}$$

(CS)

$$w=\frac{1}{48EI}\left[-3qL^2x^2+5qLx^3-2qx^4\right] \tag{14}$$

$$\varphi=\frac{1}{48EI}\left[-6qL^2x+15qLx^2-8qx^3\right] \tag{15}$$

It can be seen that the results obtained from the paper are completely approximate with other results. The relative error among above results can be explained by using different approaches.

Table. The comparison of the maximum transverse displacements at position $x = L/2$ of (SS) isotropic beams with $L/h = 5$

	$w_{\max}$		$\varphi_{\max}$	
CC	Analytical	Paper	Analytical	Paper
	0.3125	0.3126	0.9375	0.9383
	$w_{\max}$		$\varphi_{\max}$	
CS	Analytical	Paper	Analytical	Paper
	0.6480	0.6466	1.7187	1.7002

Secondly, the material of the porous beam is assumed to be steel foam with E_1 = 200 GPa, ν = 1/3. The cross section of beam is h = 0.1 m, b = 0.1 m . The normalized maximum deflections $\bar{w} = w_{\max} / h$ based on this study for two boundary conditions (CC) and (CS) are compared with other results of [23] as in Fig. 5. Again, their convergence proves the reliability of the proposed method in bending analysis of FGP beams.

Thirdly, by changing the boundary condition from (CC) to (CS) and (CF), the bending behaviors of FGP beams can be seen in Fig. 6 (a) - (c) for three types 1, 2 and 3. Once again, the effects of porosity on the bending behavior of this structure are clearly presented in these Figures. Furthermore, Fig. 7 depicts the influence of porosity on the deflections of (CF) porous beams for type 1, type 2 and type 3 respectively.

Finally, by varying the porosity coefficient e_0, the length to thickness ratio L/h and three types 1, 2 and 3, the results of the normalized transverse displacement $\bar{w} = w(L/2)/h$ at position $L/2$ of FGP beams with (CC) boundary condition are plotted in Fig. 8 (a) - (c). As the porosity value increases, the deflection of FGP beam also increases and this statement holds for all cases.

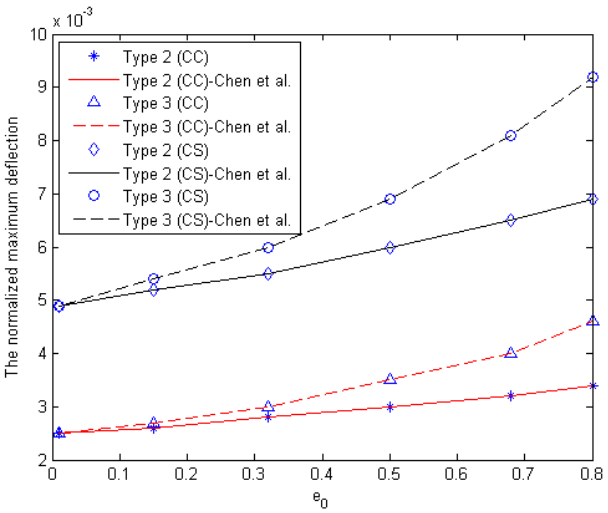

Fig. 5. *Convergence of the deflection*

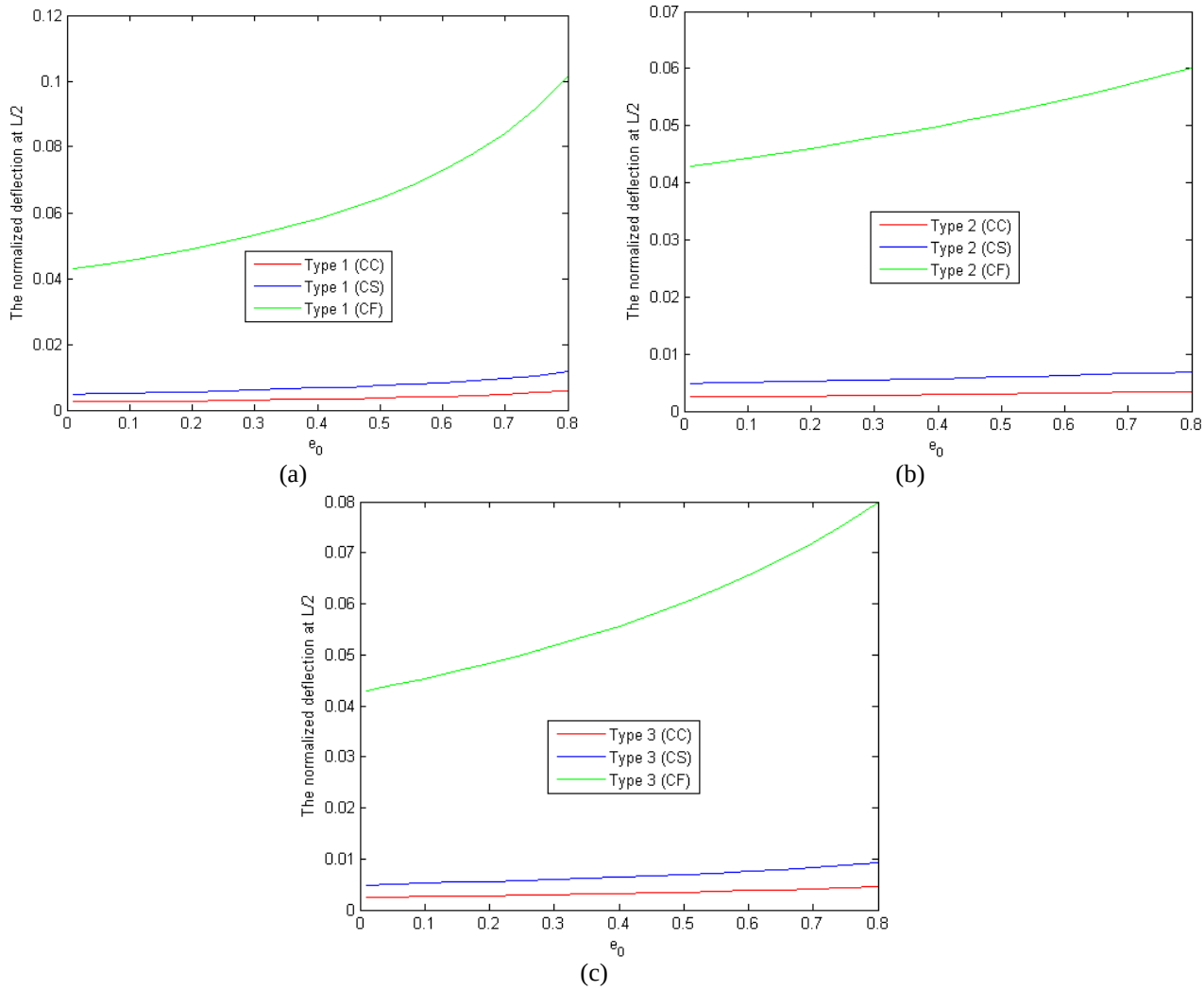

Fig. 6. *The influence of e_0 on the deflections of porous beams with (a) type 1 / (b) type 2 / (c) type 3 for three boundary conditions*

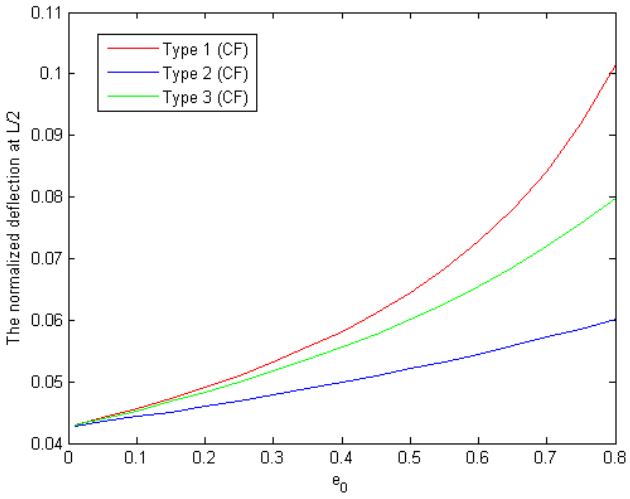

Fig. 7. *The influence of e_0 on the deflection of (CF) porous beam with three types 1, 2 and 3*

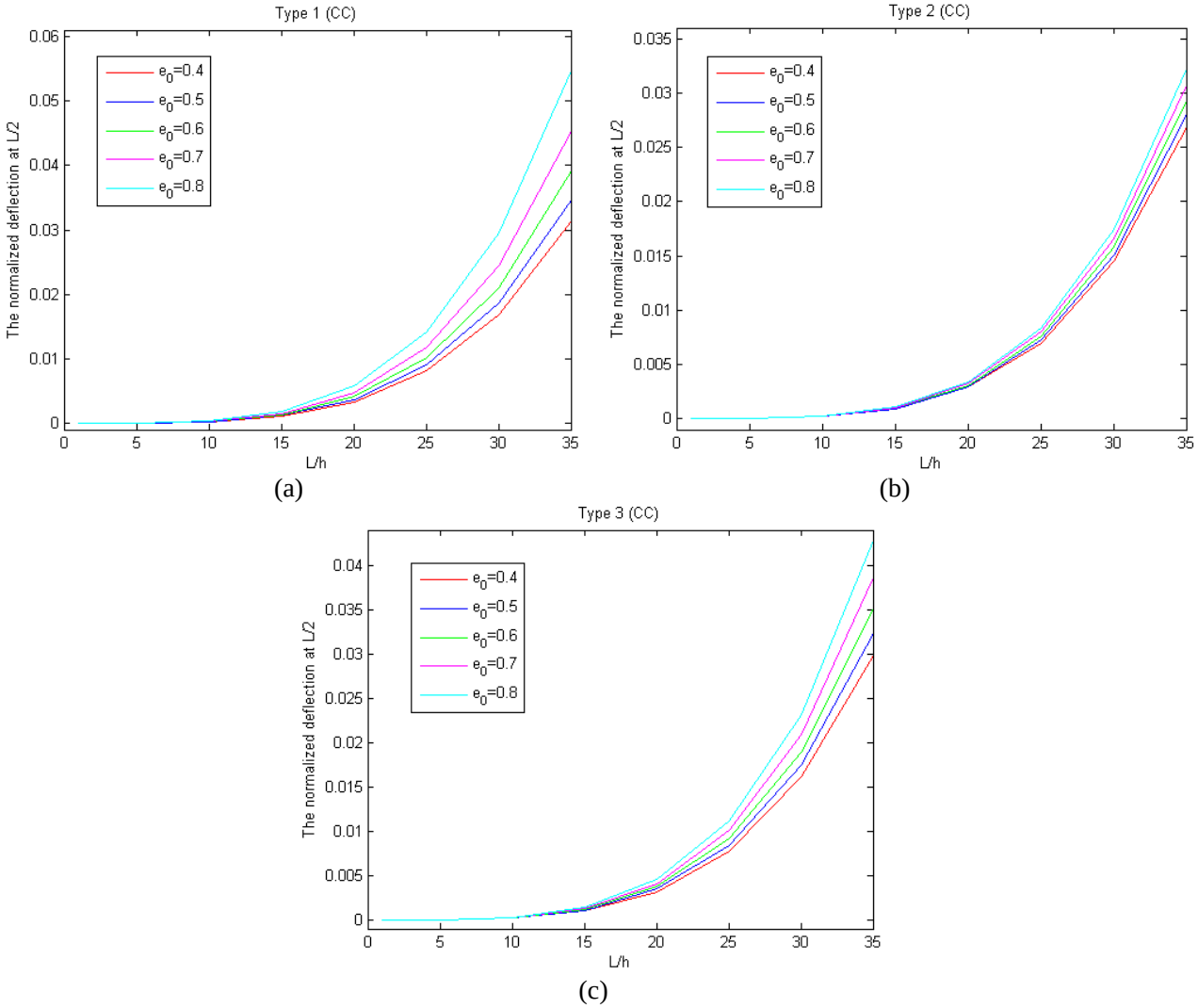

Fig. 8. *The deflections of (a) type 1 / (b) type 2 / (c) type 3 (CC) porous beams by changing ratio L/h and porosity factor e_0*

Conclusion

The bending behaviors of FGP beams under three different types of boundary condition and three kinds of porosity are presented in this study. The verification results based on this Matlab code are in good agreement

with other results in reference and the main goal of the author is to demonstrate the applicability of simple theory to analyzing the FGP beams with acceptable results.

Conflicts of Interest

No conflict of interest was declared by the author.

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Received: 13.06.2022
Revised: 20.06.2022
Accepted: 21.06.2022

DOI: https://doi.org/10.54338/27382656-2022.2-006

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ANIONIC DYE REMOVAL FROM AQUEOUS SOLUTION USING CHITOSAN - MODIFIED IRIND MINE PUMICE

In this paper, the adsorption of Congo red dye from an aqueous solution using chitosan-coated pumice (CCP) has been studied. The abundant natural pumice from Irind mine (Republic of Armenia) was successfully activated by an acid activation method and modified with chitosan. The adsorbent was applied as a low-cost, and environmentally-friendly adsorbent for Congo red dye removal from aqueous solution. The modified pumice samples were characterized by Fourier-transform infrared spectroscopy (FT-IR). To study the adsorption behavior of Congo red dye on modified pumice, the batch adsorption method was used. The effects of operating parameters on Congo red dye adsorption on modified pumice were examined, including adsorbent dose, pH, contact time, and starting concentration. Solutions of Congo red dye concentrations before and after adsorption were measured by UV-Vis Spectrophotometer (Cary-60). The wavelength of 3.799 nm^{-1} corresponds to the dye's maximum absorbance, and the obtained spectra revealed that no peak was found above the threshold after modifications.

Keywords: *surface-modified pumice, chitosan, Congo red dye, absorption.*

Introduction

The presence of dye in water has a negative impact on all living organisms. The textile industry plays a pertinent role in dye emissions into the ecosystem. Of several natural and synthetic dyes, azo group proliferation has been highly carcinogenic due to amine and benzidine emissions. In addition, the fact of being non-biodegradable makes the dye molecules last longer in the environment, producing hazards. Commonly, dyes used in the textile industry are synthetic with high resistance to oxidizing agents, biodegradation, and photo-degradation treatments [1]. Congo red dye is one of the most common synthetic dyes used in the textile industry. They are a class of benzidine-based anionic diazo dyes with high toxicity and irritant properties for eye and skin contact (Fig.1).

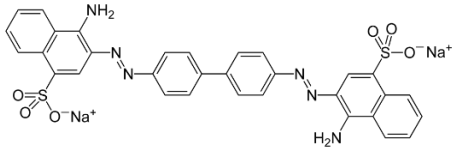

Fig. 1. *Chemical structure of Congo red dye*

At a high level of contamination, it could induce some respiratory problems and could even be carcinogenic to humans. Consequently, Congo red dye removal from wastewater is a necessity to avoid environmental issues. Various technologies have been developed to remove dye contamination from wastewater, including filtration, coagulation, electrochemical oxidation, chemical oxidation, membrane filtration, and adsorption [2].

Among all the above mentioned techniques, adsorption is considered the most feasible method to remove dye contamination in aqueous conditions [3,4]. Adsorption is a well-known separation method of high effectivity for water contaminant removal. Because of its simplicity, adsorbent reuse capability, insensitivity to harmful pollutants, high efficiency, and low cost, adsorption looks to be the most efficient technology currently available.

With its abundance and diversity of non-metallic minerals, the Republic of Armenia leads worldwide. In this study, Irind mine pumice is used as an adsorbent. Irind is located in the Talin region. It is 46 km away

from the regional center. There are perlite and pumice resources in the village, which are of industrial importance. Pumices in Armenia are classified into two groups based on their physical-mechanical characteristics: Ani pumices and lithoid pumice. The Irind mine pumice is one of the Ani-type varieties. Ani-type pumice is mainly composed of glass non-crystalline (amorphous) particles: plagioclase, pyroxene and mineral crystals, and pieces of old lava. The color is yellowish, sometimes yellow-brown or pink-yellow, and the porosity is 35–44%. It has high thermal insulation properties. The bulk density of the pumice is 0.3-0.6 g/cm^3.

Studies have shown that the pumice is composed of alumosilicates in which the amount of alkaline oxides are: SiO2 -61.54 %, MgO - 1.13%, TiO2 - 1.00%, Fe2O3 - 3.99%, K2O +Na2O - 8.18 %, Al2O3 - 16.58%, and CaO is 3.78 % [5].

The examination of the pumice by X-ray diffractometry have shown that it is a volcanic rock and is composed of cristobalite and coesite. Coesite and cristobalite are high-pressure polymorphs (crystal form) of silica (SiO2). They have the same composition but possess a different crystal structure [6].

Today, many methods have been studied to increase the adsorption capacity of natural pumice for contaminants removal from wastewater. Commonly, the materials can be modified by both physical and chemical treatment. Pumice chemical modification has changed the nature of pumice as an adsorbent for dye removal from aqueous solutions. In this study, the abundant natural pumice was activated using HCl and was modified with chitosan. Chitosan is a versatile polysaccharide widely distributed in nature (second most abundant biopolymers after cellulose) produced by alkaline N-deacetylation of chitin (Fig.2).

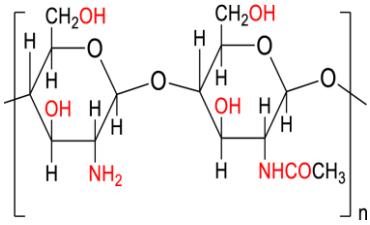

Fig. 2. *Chemical structure of chitosan*

Many application fields are described in scientific publications regarding the use of chitin, chitosan and their derivatives. Wastewater treatment using chitin or chitosan is an important application. According to this, there are many research studies that highlight the biosorbent ability of chitosan and their composites to remove pollutants from wastewater. They could be used as coagulating/flocculating agents for polluted wastewaters [7], in heavy metal or metalloid adsorption (Cu (II), Cd (II), Pb (II), Fe (III), Zn (II), Cr (III), etc.) [8, 9], and in the removal of dyes from industrial wastewater [10].

Pumice with grain sizes from 1 to 2.5 mm were used for the experiment. The materials were first ground, washed with running tap water to remove impurities, and rinsed with distilled water. Then, they were treated with 0.1 M HCl for two, three, four, and five hours. The optimal time was chosen for three hours. After three hours of acid treatment, the materials were washed with distilled water to remove excess acid until the pH of the washing water was equal to that of distilled water. The washed materials were oven-dried at 60^{o}C for four hours to evaporate the remaining water. For modification of pumice surface the powder was added to 100 ml of 3 percent acetic acid, where 3g of chitosan was dissolved. The mixture was left for 24 hours, after the pumice was filtered, washed with distilled water, and dried in an oven at 60^{o}C for 5 hours.

Results and Discussions

Fourier transforms infrared (FT-IR) spectra of the chitosan films and the chitosan/pumice films were plotted using a Thermo Nicolet AVATAR 330 FT-IR spectrophotometer (Thermo electron corporation).

FT-IR analysis of (pumice) and chitosan coated pumice was performed in order to describe the functional groups responsible for the binding mechanism between the adsorbent and the coated sample. The changes arise during the coating of pumice as presented in the Fig. 3. The FT-IR spectrum of CCP shows a predominant

broadband around 2921 and 2852 cm^{-1} assigned for asymmetric and symmetric stretching vibration of CH groups. A functional groups like –C=O, –COO were found at wave number intervals of 1626 and 1457cm^{-1}. Absorption band in the range of 1627–1450 cm^{-1} was ascribed to the vibration of carbonyl bonds (C=O) of the amide group CONHR (secondary amide) and the vibration of the protonated amine group. The limited peak at 515 cm^{-1} correlates to oscillating of the saccharide structure of chitosan [11].

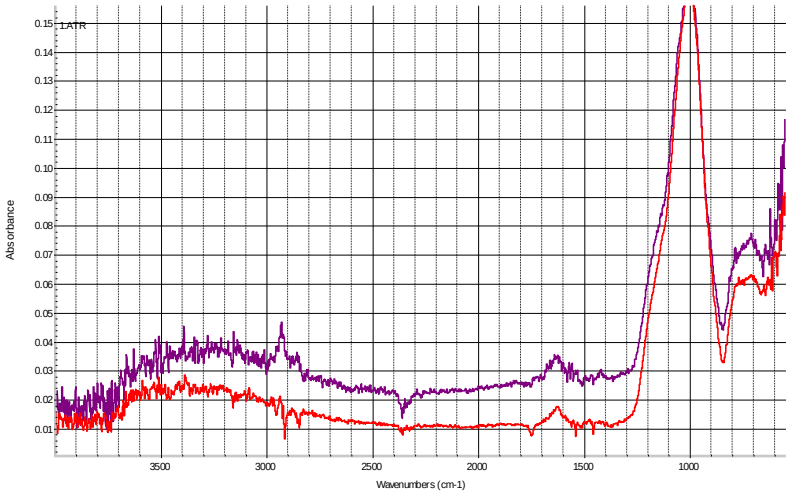

Fig. 3. *FT-IR spectra of pumice modified with chitosan (— - pumice, — - chitosan coated pumice)*

The Congo red dye adsorption tests were carried out in batch experiments by adding 1 g of an adsorbent. Typically, 0.5 g of pumice was added to a 100 ml flask containing 50 ml of Congo red dye solution at the predetermined concentration. As one of the diazo class dyes, the form of the Congo red dye molecule in the aqueous solution will be affected by the pH value. As mentioned in [12,13], the color of Congo red dye changed significantly from red to dark blue when the pH of the solution was reduced to 2. On the other hand, when the pH of Congo red dye solution was adjusted to be more than 10, its color was different from the original. Hence, in this work, the effect of the initial pH solution on the adsorption of the Congo red dye on pumice was studied at pH ranging from 3 to 9 for an initial concentration of Congo red dye of 100 mg/L. The results indicate that the adsorption of Congo red dye on the pumice was affected by the pH of the solution. The most favored adsorption process occurred at a pH of 3.9. The Congo red dye concentrations before and after adsorption were measured using UV-Vis Spectrophotometer (Cary-60). The wavelength of 3.799 nm^{-1} corresponds to the maximum absorbance of the dye. The spectra show that no peak was observed over the threshold after modification (Table, Fig. 4).

Table. UV-Vis absorbance report

Instrument parameters		Sample name (pumice)	Data before modification
Instrument	Cary 60	Peak Style	Peaks
Instrument Version	2.00	Peak Threshold	0.0100
Start (nm)	800.0	Range	800.0 nm to 200.0 nm
Stop (nm)	200.0	Wavelength (nm)	Abs
X Mode	Nanometers	205.0	3.785
Y Mode	Abs	203.0	3.799
UV-Vis Scan Rate (nm/min)	600.000		
UV-Vis Data Interval (nm)	1.00		
UV-Vis Ave. Time (sec)	0.1000		

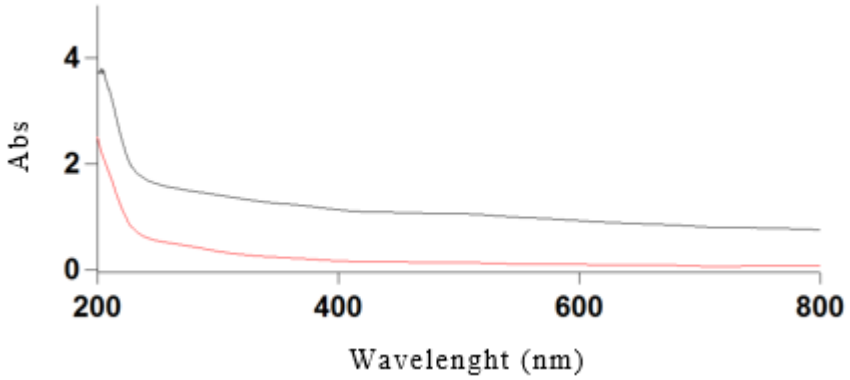

Fig. 4. *UV-Vis Spectrophotometer data*

Conclusion

The capability of acid-activated and chitosan-modified Irind mine pumice to absorb Congo red dye from aqueous solutions was studied. The characterization of the natural pumice sample before and after surface modification with chitosan showed that the structure of the natural pumice was successfully modified. The Congo red dye adsorption tests were carried out in batch experiments by adding 1 g of an adsorbent. The results show that the pH of the solution influenced the adsorption of Congo red dye on pumice. The most favored adsorption process occurred at a pH of 3.9. The Congo red dye concentrations before and after adsorption were measured using a UV-Vis Spectrophotometer (Cary-60). The wavelength of 3.799 nm^{-1} corresponds to the maximum absorbance of the dye. After modification, no peak was found above the threshold.

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Received: 19.04.2022
Revised: 23.05.2022
Accepted: 24.05.2022

DOI: https://doi.org/10.54338/27382656-2022.2-007

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BIOPHILIC DESIGN TO ENHANCE RESIDENCE COMFORT IN COVID ERA

Because of the COVID-19 pandemic, human mobility is limited, and many activities, such as work or school, are relegated to the home, including for apartment residents. As a result, this condition causes unpleasant feelings, which lead to a decline in physical and mental health. The solution from this is to improve room quality inside a limited area of apartment units using a biophilic design approach in order to create a comfortable living space for residents in a pandemic era. This research aims to critically review journals that can help architects or researchers study the ideal apartment design in the pandemic era. The anticipated outcome is the creation of opening and layout criteria that can add comfortable living for residence in a unit apartment at the same time, making it ideal to be applied. Air circulation and sun exposure are used to evaluate the opening, while room position and unit orientation are being used to assess the layout.

***Keywords**: apartment, biophilic, comfort, Covid-19, housing.*

Introduction

Pandemic COVID-19 has changed habits, lifestyles, and regulations for people in the world. This case makes every human have limitations in mobile, activities, working, school, and everything else to be done at home. So, it makes a very big change in every layer of life and has the possibility for people to get fatigued either physically or mentally due to this condition including people who lived in apartments.

Limited spaces and inadequate rooms in apartments have their own challenge to make them comfortable. People's health will receive support from exposure to nature, the sun, and fresh air [1,2]. Aside from that, preventing virus spread may be the most important thing for people today. The apartment has a sharing system, such as ducting, shafts, or corridors, which has the potential to spread the virus [3]. From this standpoint, there is a need to adjust the existing design of apartment units which already have limited space to increase their resilience towards the COVID-19 pandemic and make it comfortable for its residents at the same time. There are several strategies for solving this problem through analysis of both biophilic principles and covid-19 health protocols strategies.

This study focuses on knowing the best criteria of apartment design for facing the COVID-19 pandemic and improving the resident's comfort through biophilic theories. Biophilic was chosen because it will aid in environmental healing and performance improvement from a natural standpoint [4]. Biophilic also provides humans with a sense of comfort, calm, and healing effects on a needed dwelling [5]. As a result, it is critical for assisting people in their homes to feel happy in their daily life routine during the pandemic era. In addition, the novelty of this research is finding the design criteria of housing, especially unit apartments in the pandemic era through biophilic design in order to improve physical and mental health.

Materials and Methods

The design thinking in Fig. 1 began with a problem of limited mobility and regulation in a pandemic area and evolved into a design problem of limited space and inadequate room quality in an apartment. As a result, the design approach is to improve room quality through biophilic design using a literature review method to achieve the goal of design criteria for apartment units based on a biophilic approach in a pandemic area. Moreover, the strategy for searching the literature is to use the ScienceDirect and Google Scholar databases. The following search terms appear in the article title, abstract, or keywords: "apartment", "covid-19", "biophilic", "comfort", and "housing" with combinations like "layout" and "opening".

The next step is to screen titles and abstracts from dozens of journals that have been collected in Zotero and discussed in order to develop a strategy for extracting them into design criteria that can be used in future design strategies. The following questions were used to determine the review criteria: 1. How to make the right opening for air circulation and sun exposure in the apartment unit, 2. How to make a good position of room in apartment unit layout, 3. How to put the green area in the right place in an apartment unit.

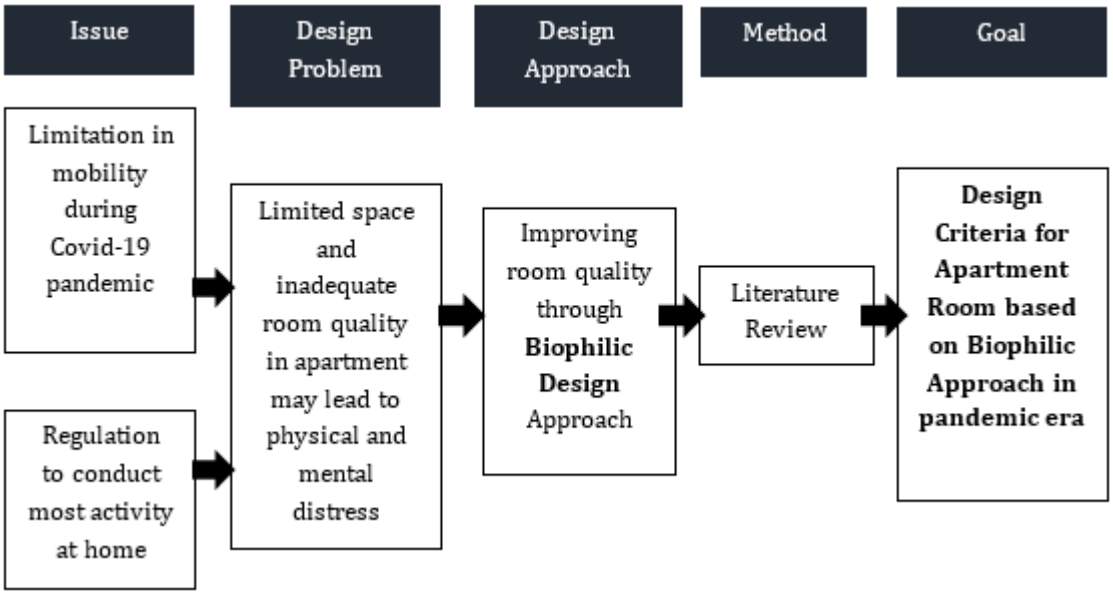


Fig. 1. *Design Thinking*

Results and Discussion

Covid-19 Health Protocol in Housing and Residential

Health protocol has become a new way of life in the world. It also occurred in housing and residential areas as a result of all the activities to be done at home. As a result, through passive design strategies, our housing and residential, including unit apartments, should adapt to this new habit. Priority design strategies should relate to connection to nature, daylight, and fresh air, such as openings for view and air circulation, daylighting, wet area placement, access to nature, and unit size or layouts that allow for physical distancing [2,6,7]. Furthermore, in housing design, there should be a separation between the uncontrollable external world and the internal personal universe that is illustrated in Fig. 2 [8]. It happened because people from outside have the potential to bring the virus or bacteria with them. As a result, they must clean their bodies before entering the living space and meeting the other families in the house.

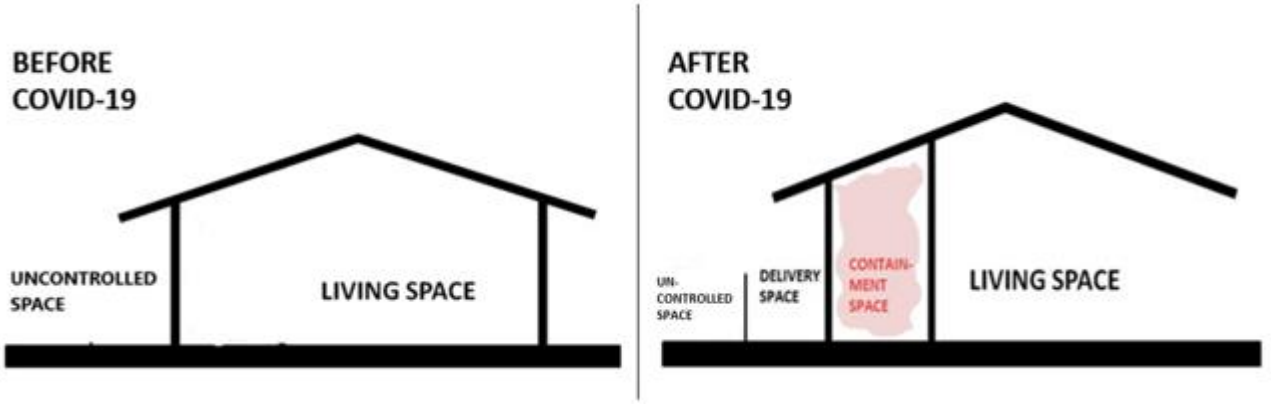


Fig. 2. *Separation Space in Between Uncontrolled Space into Living Space (Source: Spennemann, 2021)*

Unlike a landed house, an apartment is a vertical house in which there are many sharing facilities like public areas or MEP shafts. For a public area like a pool, garden, corridor, or stair, the building management can add the signage for making physical distancing through coloring codes as a marker element or put the water sink to be used to hand wash before entering the area [9]. Then, the MEP shaft is a critical point because even the dwellers don't meet each other in the building but virus can spread through the vertical shaft [3]. So, in the pandemic era, apartments should minimize the sharing vertical shaft system. Each unit should have its own system for reducing the virus spread.

Biophilic Design

Some of the health protocols for covid-19 prevention, such as providing good air circulation, natural ventilation, exposure to daylight, and connection to natural elements, have strong similarities with the Biophilic Design approach. There are several human-nature relationship theories that are related to Biophilic Design, one of them is Attention Restoration Theory. The aforementioned theory discusses that restorative settings contain features that hold their attention with little effort and restores their ability to concentrate, removing an individual from their daily tasks and allowing them to recover from stress [10]. To reach a successful application of biophilic design it is required to follow certain basic principles. They represent and include fundamental conditions for the effectiveness of biophilic design applications [11]. Those principles are:

1. Biophilic design emphasizes continuous and sustained connection with nature,
2. Focuses on human adaptations to their environment that progressively enhanced people's wellbeing over time,
3. Encourages the emotional bonds and sense of places to specific settings and places,
4. Embraces positive bonds between people and nature that heighten an extended sense of responsibility for the communities and correlated nature,
5. Strengthens mutual interconnection and integration with architectural solutions.

The embodiment of those principles can be found in the 14 patterns of biophilic design. The correlation between biophilic design principles and design patterns can be reached through those relationships as shown in Fig. 3. In the first principle, the relationship with nature can be done by making visual, non-visual, natural systems, and material connections with nature. The second principle for helping human adaptation to the environment can be achieved through providing non-rhythmic sensory stimuli, thermal and airflow variability, and dynamic and diffuse light. Third, emotional bonds and a sense of place can be encouraged by prospect and refuge. Fourth, positive bonds between people and nature through the presence of water, connection with the natural system, and also complexity and order. Last, to strengthen mutual interconnection and integration with architectural solutions is regarding prospect, refuge, mystery, risk/peril. With understanding the correlation, the architect can design the green wall, natural textured material, shadow reflection, daylight, water reflection or etc regarding biophilic design patterns. So, people can have a different experience if they do an activity in a biophilic space.

These patterns are then classified into three categories which are *natural in the space*, *natural analogs*, and *nature of the space* (Table 1). Nature in the space experience can be achieved by creating meaningful and direct links with natural elements, particularly through variative and multi-sensory interactions. Natural Analogues addresses organic, non-living, and indirect evocations of nature. Objects, materials, colors, shapes, sequences, and patterns found in nature, manifest as artwork, ornamentation, furniture, décor, and textiles in the built environment. The nature of space practices is accomplished by the creation of deliberate and engaging spatial configurations mixed with patterns of nature in space and natural analogs.

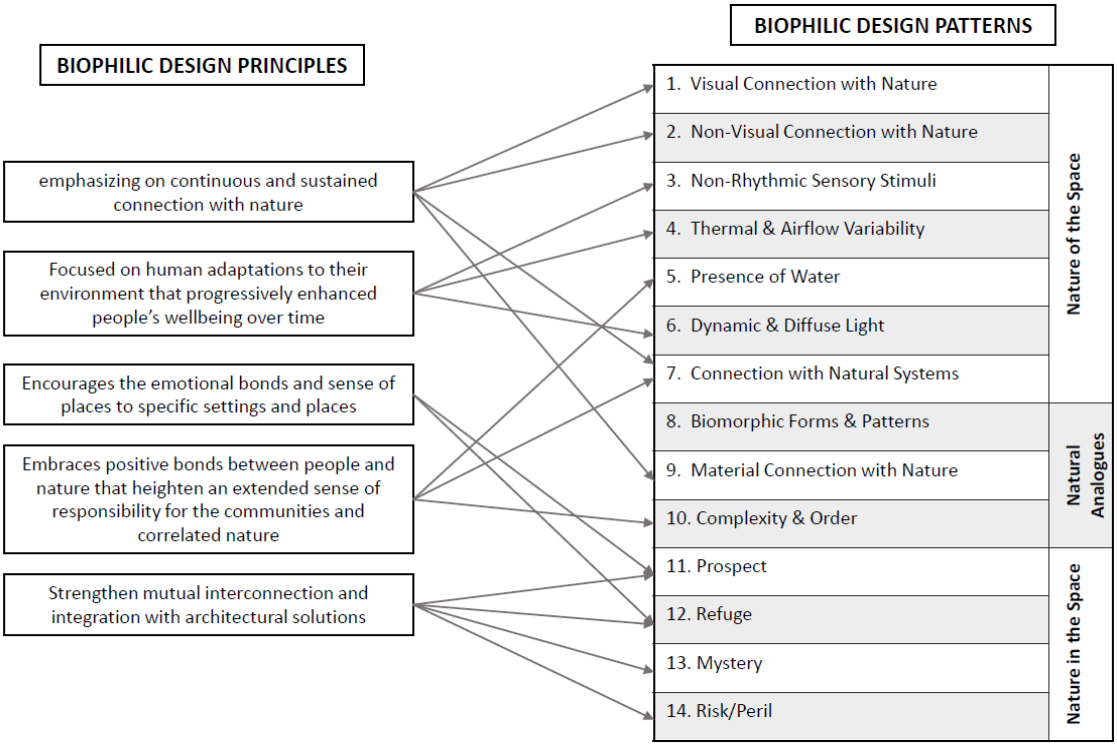


Fig. 3. *The embodiment of Biophilic Design Principles into Biophilic Design Patterns (Source: Author, 2022)*

Successful implementation of biophilic design is also expected to result in a wide range of physical, mental, and behavioral benefits. Physical outcomes include better physical fitness, lower blood pressure, greater comfort and satisfaction, fewer disease symptoms, and better health. The mental benefits range from greater satisfaction and motivation, less stress and anxiety, to better problem-solving and creative thinking. The positive behavioral change includes improved coping and mastery, increased attention and concentration, better social interaction, and less hostility and aggressiveness.

Table 1. Patterns of Biophilic Design

1. Visual Connection with Nature: view to elements of nature, living systems, and natural processes	8. Biomorphic Forms & Patterns: symbolic references to contoured, patterned, textured, or numerical arrangements that persist in nature	11. Prospect: unimpeded view over a distance for surveillance and planning
2. Non-Visual Connection with Nature: auditory, haptic, olfactory, or gustatory stimuli that refer to nature	9. Material Connection with Nature: using raw to minimum treated elements to show local ecology and create a distinction of space	12. Refuge: place in which the individual feels safe and protected, a withdrawal from environmental conditions
3. Non-Rhythmic Sensory Stimuli: Habitat, rainwater	10. Complexity & Order: rich sensory information that resembles a natural spatial hierarchy	13. Mystery: partially obscured views or other sensory devices that attract persons to explore further
4. Thermal & Airflow Variability: moderate levels of sensory variability in the environment		

5. Presence of Water: enhancing experience of a place by seeing, hearing, or touching the water		
6. Dynamic & Diffuse Light: variation of light and shadow intensities that change over time as it happens in natural settings		
7. Connection with Natural Systems: awareness of natural processes, especially seasonal and temporal changes characteristic of a healthy ecosystem		

Source: Author, 2022

Design Criteria for Apartment Units

Implementation of biophilic design principles and covid-19 prevention in the design of apartment units needs more concrete and measurable steps. The first step is to filter the biophilic design patterns that will be utilized based on the suitability of application in the context of apartment units. Based on the analysis in Table 2, there are eight biophilic design patterns that are suitable for covid-19 health protocols analysis. Thermal and airflow variability is related to opening presence both for daylight and fresh air and also independent ventilation system in each unit apartment. Visual connection with nature and connection with the natural system is correlated with opening for daylight, fresh air, and view indirectly. In non-visual connection with nature, daylight is not considered but the opening is important to enter the fresh air. Last, biomorphic forms and patterns, material connection with nature, and refuge can relate to space partition design in containment space. Selected patterns are then applied to the design through the help of proposed design criteria.

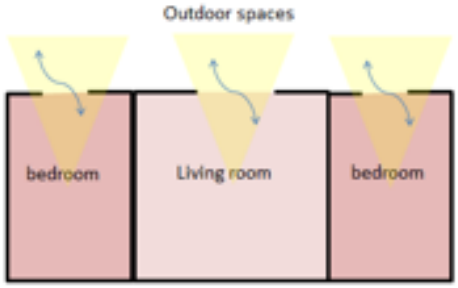
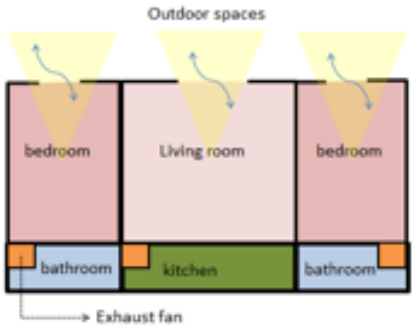
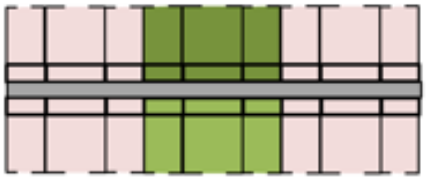
Table 2. The Correlation Between Biophilic Design pattern with COVID-19 Health Protocols

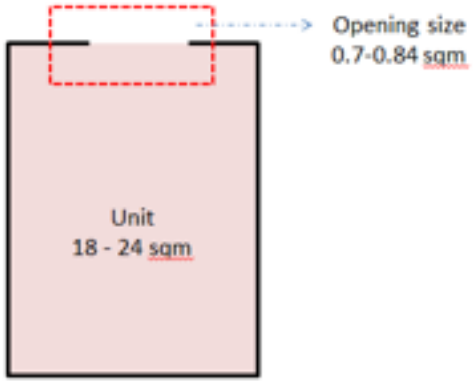
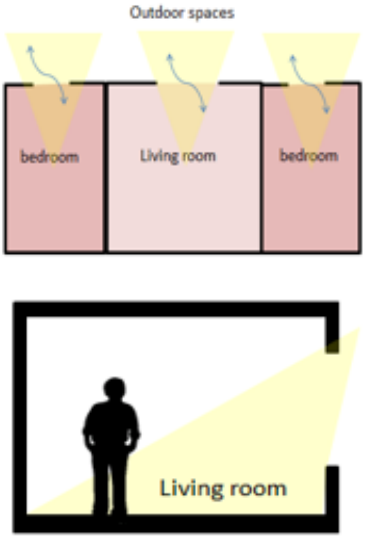
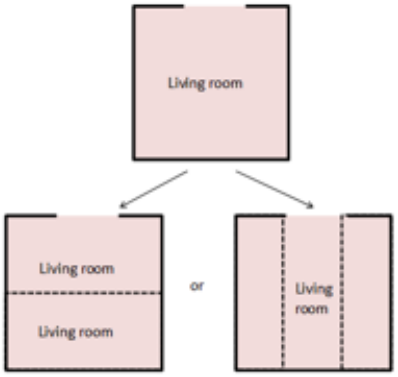
Biophilic Design Pattern		**COVID-19 Health Protocols**			
		Opening for daylight	Opening for fresh air	Space Partition	Independent Ventilation System
1.	Visual Connection with Nature	V	V	-	-
2.	Non-Visual Connection with Nature	-	V	-	-
3.	Non-Rhythmic Sensory Stimuli	-	-	-	-
4.	Thermal & Airflow Variability	V	V	-	V
5.	Presence of Water	-	-	-	-
6.	Dynamic & Diffuse Light	V	-	-	-
7.	Connection with Natural Systems	V	V	-	-
8.	Biomorphic Forms & Patterns	-	-	V	-
9.	Material Connection with Nature	-	-	V	-
10.	Complexity & Order	-	-	-	-
11.	Prospect	-	-	-	-
12.	Refuge	-	-	V	-
13.	Mystery	-	-	-	-
14.	Risk/Peril	-	-	-	-

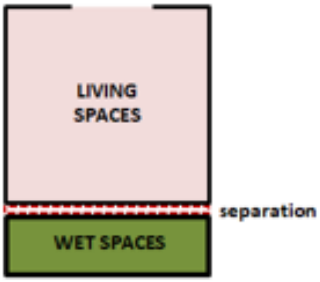
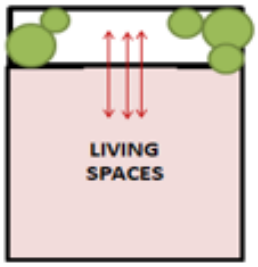
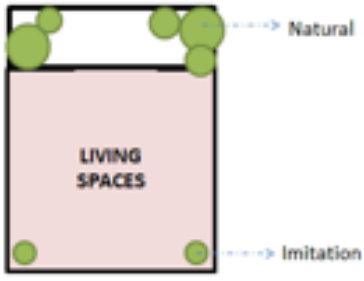
The design criteria for apartment units are created by reviewing many journal articles in order to determine several aspects, such as the facade/window opening, layout configuration, and presence of green spaces. All

three are needed because they can make the design that refers to biophilic design principles as mentioned before and also health protocols during pandemic covid-19. Table 3 is the reference synthesis that can be used for a proposed design.

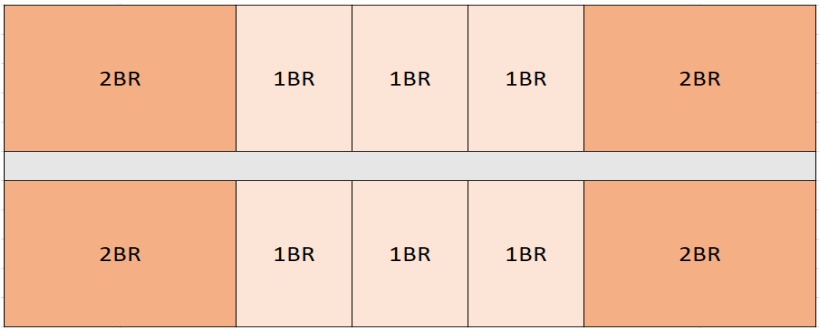
Table 3. Reference findings and synthesis

No	Findings	Reference	Proposed Design Criteria
	A. Façade/Window Opening		
1.	The use of daylight in the workplace showed the possibility of reducing the feeling of fatigue. It is interesting to note that although the presence of greenery has an impact on the subjective perception of drowsiness, physiological tests indicate that the presence of daylight has an objective impact on the reduction in drowsiness. Daylight is needed to refer to biophilic design patterns such as visual connection with nature, thermal and airflow variability, dynamic and diffuse light, connection with natural systems. Daylight is also in COVID-19 health protocols necessary.	[4]	Providing sufficient windows and openings which allow daylight to reach the work/study that make shadow reflection and also natural light in the room. Through daylight, the room will keep the humidity so that it avoids virus accumulation. 
2.	Natural ventilation through window openings is preferable to mechanical ventilation. It will allow changes in air and daylight to enter the house. The room should have a high humidity level so that viruses and particles do not stick to it. If there are some rooms with mechanical systems, they should have speed exchanges so the air can change quickly (covid-19 health protocols). Natural ventilation is also needed in biophilic design patterns in visual connection with nature, non-visual connection with nature, thermal and airflow variability, connection with natural systems.	[12-14, 2]	Providing natural ventilation and window opening in work/study/bedroom/living area and mechanical system with the exhaust in bathroom or kitchen. Opening in a room also changes the air process and makes a room healthier. 
3.	Natural ventilation in a tropical climate is considered pleasant when the opening faces north or south and the flow of air indoors varies between 0.6-1.2 m/s. Natural ventilation is needed in biophilic design patterns and also in covid-19 health protocols.	[15]	The layout of the building should optimize the north-south orientation. If not possible, some design treatment should be applied to avoid direct exposure to east-west sunlight. 

4.	The minimum value of Air Change per Hour (ACH) to reduce virus spread via aerosol ranged between 0.5-1.0 $ACH = (Q/V)*3600$ V: room volume (m^3) Q: natural ventilation value (m^3/s) $Q = 0.025*A*v$ A: opening area (m^2), v: velocity at opening (m/s) 0.025: multiplying factor (constant) The opening is needed in covid-19 health protocols for making an independent ventilation system for each unit apartment that is related to airflow variability in the biophilic design pattern.	[15]	Required opening size between 0.7-0.84 m^2 for a unit with a floor area 18-24 m^2 (common size for studio unit) 
	B. Layout Configuration		
1.	The use of daylight in the workplace showed the possibility of reducing the feeling of fatigue. It is interesting to note that although the presence of greenery has an impact on the subjective perception of drowsiness, physiological tests indicate that the presence of daylight has an objective impact on the reduction in drowsiness (biophilic design pattern). As mentioned before, daylight is also needed in covid-19 health protocols.	[4]	The layout arrangement should locate the work/study area as such to receive proper daylight 
2.	People are forced to stay at home due to the lockdown regulation. As a result, all activities will take place in the house, altering each family member's privacy (covid-19 health protocols). To bring connection with nature, the room should be considered with biomorphic form and patterns, material connection with nature, and refuge.	[7,14,16]	The living room should adapt to this condition in order to create a flexible room with element nature material. 

3.	To prevent the virus from spreading, the WHO recommends separate sanitation. Furthermore, a buffer or containment space between the uncontrollable external world and the internal personal universe must be established (covid-19 health protocols). To bring connection with nature, a separate room should be considered with biomorphic form and patterns, material connection with nature, and refuge.	[8,14]	The housing layout strategies should have a separate room for cleaning the body before entering the main live spaces in the house. In a separate room can apply the material that connect with nature and give a safe feel for people to clean their bodies from viruses that bring outside. 
4.	The room should have access to nature to assist people in treating their mental and physical health (biophilic design pattern). Opening for accessing the nature outside is needed for covid-19 health protocols due to daylight and fresh air requirement.	[2,7]	The live spaces should have direct access to the greenery area either balconies or vertical gardens. The opening is needed here for accessing the greenery, daylight, and fresh air. 
	C. Presence of Green Space and Natural Element		
1.	There is a decrease in stress levels and increased wakefulness in the afternoon with the presence of greenery (biophilic design pattern). As mentioned before, the opening is needed for accessing greenery and fresh air.	[4]	Locate greenery or green space either natural or imitation nearby work/study area. The opening is needed for accessing greenery outside and also for getting fresh air from outside. 
2.	Housing design strategies should prioritize more livable spaces with views of green space (biophilic design pattern). Greenery is also helping the fresh air requirement for helping fresh air supply in unit apartments (covid-19 health protocols).	[6]	The balconies can be used to put the natural green spaces. 
Source: Author, 2022			

The next step is an elaboration of synthesis of proposed design criteria into an easy-to-read guideline. The previous criteria, then simplified into the following notations: window/opening = A, layout configuration = B, and presence of green space = C. Come after each criterion are the number of proposed points in accordance with Table 3. The guideline can be seen in Fig. 3 for 1 BR and Fig. 4 for 2 BR. Furthermore, in the wet area, there is ducting for helping exchange air circulation in the wet area. The ducting system is made individually for each unit. This purpose is to avoid the virus spread which is vulnerable to occur if a sharing system is made.



Keyplan

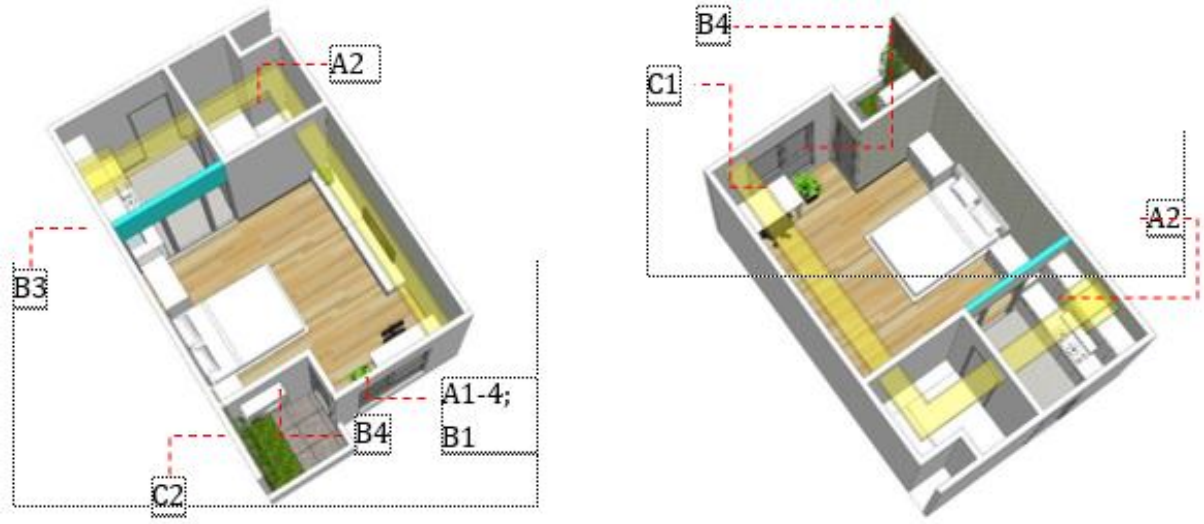


Fig. 3. *Guidelines for studio/1BR unit*

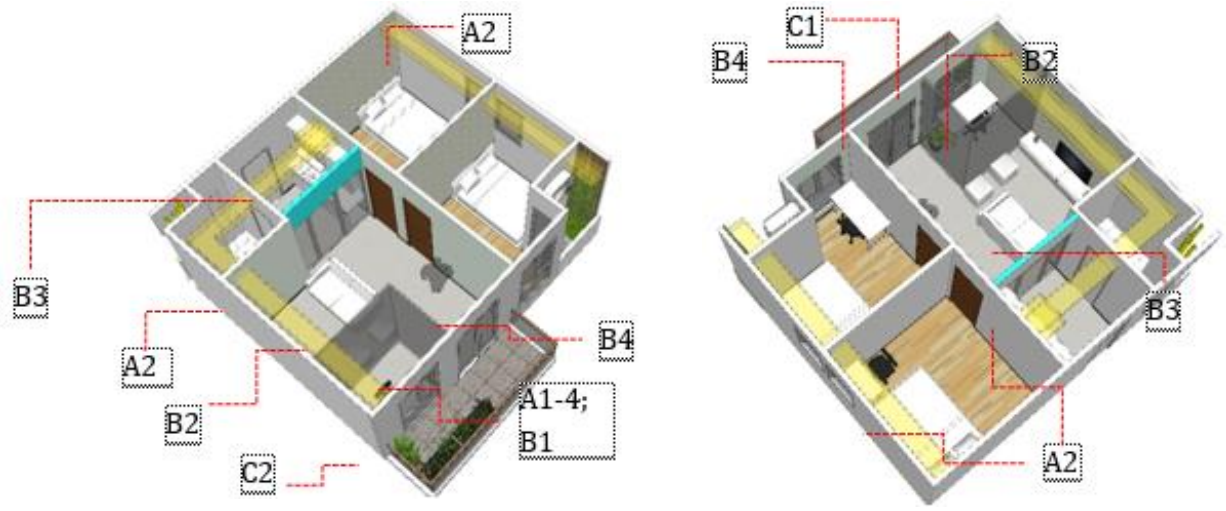


Fig. 4. *Guidelines for 2BR unit*

Conclusion

Pandemic covid-19 is unavoidable and will last for a long time. As a result, as a human, it is critical to co-exist and anticipate virus spread, including in the home. One way to deal with it is to arrange for a comfortable place to live. Furthermore, biophilic is used to improve the resilience of buildings, both physically and mentally. Here is the conclusion of the research literature that was conducted:

1. Openings for air circulation and natural light are essential. The air should change quickly, and sunlight should enter the living areas. This is to avoid the high humidity in the room, which can make viruses easily stick.
2. Because of the opening requirement, the layout room, particularly for lives and work, should be located to receive adequate daylight and natural light. Furthermore, the layout of the space must be flexible in order to meet the needs and privacy of all activities carried out at home.
3. Layout design necessitates the separation of wet and living spaces. The wet area is close to the door so that visitors from outside can easily clean their bodies before meeting the rest of the family in the house.
4. Existing greenery should be placed near living and working areas. During a stay at home, it is necessary to bring calm and refreshment to the surroundings. The possible space to put greenery is in the balcony or service ledge for the outdoor AC unit. Hence, the balcony becomes an indispensable feature to be provided in an apartment unit.

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Received: 22.03.2022
Revised: 31.03.2022
Accepted: 01.04.2022

DOI: https://doi.org/10.54338/27382656-2022.2-008

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ARCHITECTURE STAGES AND FEATURES OF COMPOSITIONAL FORMATIONS OF KHACHKARS

The article touches upon the origin of khachkar art, symbolism, stages of compositional development, as well as characteristics of artistic means. Since the 9th century, khachkar art has become a means of expressing the spiritual aspirations, religious perceptions and ideas of the Armenian nation. Thousands of khachkars, being one of a kind, are scattered not only throughout the Republic of Armenia and Arcakh, but also in the territory of Historical Armenia, including Turkey and Nakhichevan, as well as the Armenian colonies. Unfortunately, thousands of khachkars have been destroyed by vandals, who have tried and are trying to erase the Armenian trace outside the territory of present-day Armenia. The study aims at systematical presentation of the sequence of the phased development of khachkars, the compositionl, ornamental and national features typical of each period. We think that any research devoted to those purely Armenian monuments is still up-to-date and can enrich the list of scientific works dedicated to Armenian culture.

Keywords: *khachkars, monumental art, sculpture, floral and geometric ornamental motif.*

Introduction

Khachkar art has always been in the spotlight of the Armenian and foreign scientists in various cultural directions. The monuments were studied by art critics, historians, archaeologists, lithographers and architects. Numerous studies are devoted to Armenian khachkar art: monographs, scientific dissertations, articles and film series. Noteworthy are the Babken Arakelyan's, A. Shahinyan’s, A. Jacobson’s, M. Hasratyan’s, S. Mnatsakanyan's and others' published researches. Expert of sculptures Samvel Karapetyan, author of the book and the film "The Khachkars of Jugha" (1995), has a great contribution to the study of khachkars of Jugha. Khachkars are widely studied by historian Hamlet Petrosyan. In his book "Khachkar" (2008), issues, related to the origin, function, ritual, meaning behind composition and symbolism of khachkars are addressed. The studies and publications devoted to separate khachkars are numerous too. In his book "Problems of Armenian Medieval Folk Culture. Khachkar”, Artsruni Sahakyan touches upon the topic of cross and cross worship after the adoption of Christianity in Armenia. Numerous illustrated books have been published, out of which the "Khachkars" by photographer Hrayr Baze Khacheryan, the "Armenian Decorative Art" by co-author Armen Kyurkchyan, etc. are noteworthy.

The researches are mainly conducted by historians and art critics. However, there are a number of issues related to the architectural composition of khachkars, the formation and development of ornamental sculptures, as well as to this unique type of monumental art in Armenia as a small architectural style, which should be elucidated and interpreted.

In this paper, an attempt has been made to systematically present the preconditions for the creation of khachkar art, types of khachkars, stages and peculiarities of the composition development as well as through comprehensive analysis to observe the link between supplications and borrowings with the previous stages. Studies devoted to khachkar art are of great importance, as thousands of these sculptural stone monuments of the Christian period are scattered throughout the territory where the Armenian people lived and created.

Materials and Methods

Armenian and foreign scientific literature, archival materials and photographs as well as measurements were studied. Comprehensive research, comparative and situational analyses have been carried out.

Results and Discussions

Khachkar art is one of the valuable achievements of the Armenian culture. Due to its compositional and ideological significance, khachkar has certain similarities with the vertical stone structures created in the Armenian plateau at different historical stages (dragon stones, phalluses, stone monuments of Urartian and ancient periods with inscriptions, obelisks of the Christian period, quadrangular monuments, winged stone crosses) many of which are created of single-piece stone and have a vertical position [1]. Many researchers consider dragon stones as a prototype of a khachkar. Not denying the distinct similarities between the mentioned monuments, it should be noted that khachkars generally belong to the series of monuments made of a single-piece stone as well, erected vertically, however, ideologically, semantically, symbolically and compositionally khachkars can be considered to be unique and exceptional monuments of the Christian period in Armenia, which are true national manifestations entrusted by the Armenian people to the treasury of the world culture. The compositional center of a khachkar is the cross, which became the main symbol of Christianity after the adoption of Christianity in Armenia. After the crucifixion of Christ, the Cross symbolizes eternal life, the victory of Jesus Christ over Satan and sin for the salvation of mankind. It is worth mentioning that one of the five Feasts of the Armenian Apostolic Church is the Feast of the True Cross, celebrated to commemorate the return of the Jesus Christ's True Cross to Jerusalem from Persian captivity and its erection in Golgotha. According to Grigor Tatevatsi, the True Cross became the bridge connecting the abyss between Heaven and Earth, "the one who opens the gates of paradise and gives the kingdom of heaven as inheritance".

A number of churches have been given the name of Surb Khach (Holy Cross) (Kasagh Basilica, 4th-5th centuries, Akhtamar church of 9th century, Armenian churches in Akhalkalaki, Damala village of 19th century in Georgia, etc.). It can be said that in medieval Armenian culture, the cross became a symbol of Christianity as an object of worship, in contrast to neighboring Christian countries (Byzantium, Syria, Georgia), where icons were widely worshiped. Cross worship is one of the special manifestations of Christianity among the Armenian people.

In the period of early Christianity, the symbolism of the cross became one of the main themes of Church doctrine. Many odes were dedicated to the Cross, for example, the marvelous odes of the Armenian philosopher of the 6th-7th centuries David Anhaght's hymn to the Holy Cross, where the cross is represented in a form of a wonderful tree that grows from the earth, reaches the sky and fills the whole Universe with its fruits.

The cross, as an ornament, became the main pattern of khachkars since the 9th century. It symbolizes the Tree of Life. Until the 9th century, the cross was mainly presented in the form of winged crosses standing on a pedestal or obelisk. The origins of khachkar art can be traced back to the compositions carved on the pedestals of the early medieval quadrangular monuments and winged crosses crowning them, as well as to the ornaments of the church portal lintels and windows [2].

As monuments khachkars were erected in important historical places, sanctuaries, on graves, near churches and sometimes inside the church walls. Over the time, khachkars were attributed a number of meanings, according to which they are divided into three groups.

- Memorial khachkars, placed in cemeteries near a tombstone facing west (khachkars of Noratus, Saghmosavank, Old Julfa, cemeteries of monastic complexes).
- Worship khachkars placed in sanctuaries, in the areas of monasteries and churches (the Amenaprkich (All-savior) of Haghpat, the two khachkars of Dadivank, the embroidered khachkars in Goshavank, etc.).
- Monumental khachkars, erected to glorify an important historical event (the khachkar erected on the occasion of the liberation of Amberd Fortress from Seljuks, khachkar of Arajadzor in Artsakh, etc.) [3].

The following periods of khachkar art development can be distinguished: 9-10th, 11th, 12-13th and 14-17th centuries [4].

The earliest khachkars (9-10th centuries). In the 9-10th centuries, after liberation from the Arab conquest, the cultural life, such as architecture, miniature painting, fresco painting, sculpture as well as khachkar

art began to prosper in Armenia. Among the first khachkars are the khachkar of 866 located in the graveyard of the "Eghtsu Ktor" chapel of Vaghuhas village in Artsakh, the khachkar of 876 of Hortun village in Ararat region and the khachkar of 879 erected by Ashot Yerkat's wife Queen Katranide in Garni village (according to the monument expert Samvel Karapetyan). Among the first khachkars are "Murad Khach" khachkar erected in Mets Masrik in 881 by prince Grigor Atrnerseh of Syunik, the khachkar of Makenyats monastery (9th century), numerous khachkars in the territory of Talin (882), Kechut (886), Tatev (895-906), Artsakh, etc. (Fig. 1).

Khachkar, village Vaghuhas, Artsakh, 866 | *Khachkar, Hortun village, 876* | *Khachkar of Queen Kadranide, 879* | *"Murad Khach" khachkar, 881* | *Khachkar of Makenyats Monastery (now Etchmiadzin), 996*

Fig. 1. *The earliest khachkars. 9-10th centuries*

The above-mentioned khachkars are mainly monolithic stone slabs (basalt or tuff), which are attached to the stone pedestals with protruding edges at the bottom. They are also often erected into the ground without a pedestal. Rectangular slabs are common too, but mainly extending upwards, with a circular composition at the top, encircled in an edging pattern along the entire perimeter. Like the altars in the church, khachkars are facing west too. The main decoration is the cross, carved on the central vertical axis of the western surface, on the basis of which the word "khachkar" is originated. Cross carvings have two wings with round balls – buds. Grape, pomegranate and other ornaments are depicted on the upper wing of the cross, and palm leaf ornaments rise from both sides of the lower wing, barely connecting at the horizontal wings of the cross. As symbols of Christianity, pomegranate and grapes become one of the important motifs of khachkar ornaments [5]. Stair-like bases or rosettes were carved on the lower section of the cross. Sometimes these stair-like bases were sculpted with lily or palm leaf ornaments. Later khachkars, of course, underwent some changes, preserving the main characteristics of the composition with the central cross sculpture.

From the earliest times, inscriptions were engraved on khachkars to document important historical events. Later on, the sculptor's name was engraved on khachkars too, next to the name of the person who ordered them. Mkhitar Kazmogh (12th century), Momik, Poghos (13th century), Kiram Kazmogh (16-17th centuries) and others.

Khachkars of the 11th century. Since the 11th century, the development of a rich variety of khachkar ornaments has been evolving quite rapidly. The sculpted central cross was encircled in the rectangular, arched edging at the top. The khachkar ornaments of this period continue to attach importance to the grapes and pomegranate coming down from the cross wings, and already a better styled palm ornament at the bottom, while the trim encircling the main cross throughout its entire perimeter is enriched with various geometric ornaments which are not repeated even in the same khachkar. Later, these ornaments, with their elegant, complex and diverse solutions, become the expression of not only khachkars, but also the artistic content of decoration of worship structures (Fig. 2).

Tsaghats qar, 1041 *Haghpat, 1023* *Bjni, 11th century*

Fig. 2. *Khachkars, 11th century*

Khachkars ending in cornice or frieze at the top appeared since the end of the 11th century. These were mainly of two types. The main feature of the first type was the upper part of the khachkar slab processing in a form of a plane pushed forward. In the second the khachkar slab was crowned with a frieze at the top, which was attached to the khachkar with iron nails or with special protrusions made on the top of the khachkar. The frieze was often decorated with various floral, geometrical or sculptural ornaments.

Khachkars of the 12-13th centuries. The 12-13th centuries were the heyday of khachkar art. Numerous masterpieces of khachkar art were created all over Armenia, decorated with high-art ornaments of various shapes and contents. At that period, anchor and pedestal were also of great importance. The pedestal could be multi-level, sometimes sufficiently high and richly decorated. This type placed a special emphasis on the monumentality of khachkar. It acquired a dominant, solemn appearance, and seemed higher than its actual height, increasing and emphasizing the significance and impact of the monument.

Geometric ornaments predominated, which were the basis for the trims encircling the cross. Ornaments of this period, with their variety, unique, diverse solutions of original ornamental motifs, give luxury and majestic elegance to khachkars with woven, embroidered ornaments, bringing khachkar art to perfection. The ornaments are repeated in unison in the exterior decoration of the church buildings of those eras, in portal lintels, decorative patterns of belts and arches [6].

From the end of the 12th century, icon sculptures became popular in the composition of khachkars, including images of Christ, Madonna, saints, angels and apostles. As compared with the neighboring countries, where the worship of illustration sculpture was manifested mainly in the form of mosaic and fresco icons, in Armenia it was expressed through the composition of khachkars. In neighboring Byzantine, illustration art was mostly expressed in the form of mosaics [7]. It dates back to the ancient times, reaching to perfection in St. Sophia Cathedral in Constantinople, in Church of San Vitale in Ravenna, in St. Mark Cathedral in Venice, and in many other places of worship (Fig. 3). In Georgia, icon art is mainly manifested in frescoes. The walls of medieval Georgian churches are decorated with colorful biblical-theme frescoes [8].

Mosaics of St. Sophia Cathedral in Constantinople and of St. Mark Cathedral in Venice

Fig. 3. *Byzantine mosaics*

The icon sculptures of Holy Mother of God, saints, apostles, angels enrich and more intensely sanctify the worship of the cross in Armenia, appearing in the compositions of khachkars. One of the best examples are

khachkars of Noravank, some of which are created by a medieval genius master Momik (Fig. 4). There are also icon sculptures on secular themes.

Fig. 4. *Momik's Khachkars in Noravank*

Starting from the end of the 13th century khachkars, known as "Amenaprkich" (All Savior) were created, the main cross of which depicts the scene of Christ's crucifixion (khachkars of Haghpat, Dsegh, Etchmiadzin, Marts, Sevanavank, etc.) (Fig. 5).

Haghpat khachkar, 1273

Ararat Province, Jghingyol village, 1279

Lori province, Marts village, 1285

Fig. 5. *"Amenaprkich" khachkars, end of the 13th century*

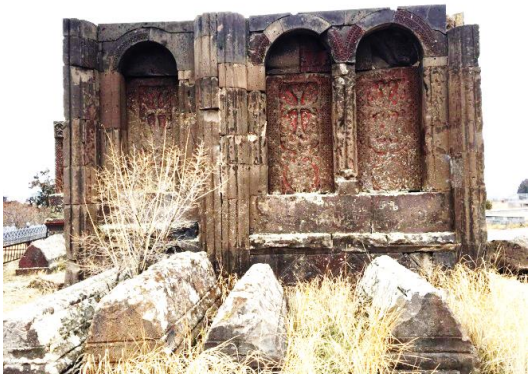
Starting from the 12th century group khachkars were found, which were placed on general or separate pedestals (Kecharis, Havuts Tar, Geghard, Haghpat, etc.). Khachkars carved on natural rocks are of great interest as well (Fig. 6).

Yeghvard, 1160

Kecharis, 12th century

Fig. 6. *Group khachkars*

Starting from the 12th up to the 14th centuries, khachkars, enclosed in walls, completely embedded in a polished stone niche, crowned with a double or single-slope roof, were found (Fig. 7). Khachkars enclosed in walls were attached to the church walls as well. The khachkars carved from rock fragments or on natural rocks (the rock-cut khachkars of Geghard Monastery, Garni, Vayots Dzor, Vardenis) are unique too.



Eghvard, 13th century

Hovhannavank

Fig. 7. *khachkars enclosed in walls*

Khachkars of the 14-17th centuries. The cemeteries of Noratus and Old Jugha (Nakhichevan) of the 15th-17th centuries are among the pearls of khachkar art, which are sculptural "forests" of different khachkars (more than 100000) (Fig. 8) [9]. The khachkars and tombstones of New Jugha were completely destroyed as a result of the vandalism organized by Azerbaijani authorities at state level in 2005, leaving only photos, footages, and other undisputable information [10].

Noratus khachkars

Old Jugha Khachkars

Fig. 8. *Cemeteries of Noratus and Old Jugha of 15-17th centuries*

Conclusion

1. Taking into account the compositional features of khachkars, the types, formed and developed in the middle Ages, i.e. in the 9-17th centuries can be distinguished. They were:
   - The khachkars of the early period, which had a simple composition - a single-piece stone extending upwards, mostly rounded at the top. They did not have a pedestal, sculpted main cross was placed in the center, all the edges end in circular balls.
   - Khachkars made of single-piece stone and placed on a rectangular or ladder-shaped pedestal, the surface of which was sometimes sculpted.
   - Khachkars, enclosed in walls, embedded in niches, as well as inside the church walls or natural rocks.
   - khachkars with cornice or frieze, the surface of which was also decorated with ornaments.
   - Group khachkars (sometimes placed on a common pedestal) and khachkar fields.
2. The main role in the khachkar ornament is attributed to the sculpted main cross. The pomegranate, symbolizing Christianity, grape clusters, palm leaf ornaments, various and multifaceted geometric

ornament motifs that are not repeated even in the same khachkar, icon sculptures and valuable inscriptions are of great importance too.

3. Over time, the khachkar acquired a three-part composition:
   - a pedestal that symbolizes a person's heavenly, temporary life,
   - the main part (mainly included in the altar), which symbolizes the faith, the way to the eternal kingdom, decorated with the main cross and the ornaments symbolizing Christianity,
   - frieze, which symbolizes eternal life, paradise decorated with icons, floral and geometric ornaments.
4. Thus, it can be concluded that khachkars belong to the Armenian memorial art of the Christian period. And if the monuments of the historical periods, having lost their functional significance over time, became solely the bearers of the culture of given periods, khachkar art continues its development, being a product of the Armenian national thought. It has acquired national value, occupying its unique place in the treasury of the world culture.

Thousands of khachkars created over the centuries differ from one another. Each khachkar is the integrity of master mason's imagination and emotions, manifested through the ornament motif having no analogues. Under the rubric "Armenian khachkar art. The symbolism and craftsmanship of the khachkar", it has been included in the UNESCO list of the intangible cultural heritage of humankind. As a stone proof of the rich culture of the centuries-old history of the Armenian nation, khachkars continue their historical procession even nowadays preserving their practical and artistic significance.

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Received: 17.03.2022
Revised: 20.03.2022
Accepted: 10.04.2022

DOI: https://doi.org/10.54338/27382656-2022.2-009

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VERNACULAR ARCHITECTURE IN ARMENIA, FROM TRAVELERS' ACCOUNTS, IN THE WESTERN CONTEXT, FROM THE 17th CENTURY TO THE PRESENT DAY

The corpus of accounts by European travelers who visited Armenia (Fig. 1), *extracted from A. Marouti's research, as well as various writings by authors - Armenian architects during the Russian then Soviet period - will serve as a starting point for this research. Its objective is to put two questions in parallel: what consideration of vernacular constructions as genuine architectures in Armenia; and how this interest is situated about these architectures in the West. Using the Timelines tool, a chronological comparison ("side by side" in French) allows us to identify Soghomon Vardanian as a precursor to the recognition of the vernacular.*

Keywords: *travelers' accounts, popular constructions, architectural heritage, Armenian vernacular legacy, cultural landscape.*

Fig. 1. *Yerevan by Jean Chardin, Voyages of Monsieur le Chevalier Chardin in Persia and other places in the East, Amsterdam, Jean-Louis de Lorme, 1711 (available on googlebooks)*

1. The popular constructions put in the background in the literature on Armenian architecture

Introduction

The objective of the *research-transformation* [1] that I initiated in favor of earthen architectures in Armenia is to reactivate interest in these constructions by trying to transform the way people look at this ancestral material, in Armenia, but also in France [2]. Knowing that this type of construction is experiencing a resurgence of interest in Europe and all over the world, in particular in the current context of the Anthropocene and ecological requirements - as evidenced by French experiences, for example: that of architect C. Vergély in the Confluence district of Lyon[1] or the project of the Joly et Loiret agency in Ivry, near Paris[2].

[1] https://www.batiweb.com/actualites/eco-construction/le-pise-ce-materiau-ancien-aux-normes-ecologiques-modernes-2019-05-03-34583

[2] https://www.lemonde.fr/planete/article/2018/07/05/construction-le-retour-a-la-terre-tente-les-villes_5326293_3244.html

One of the starting questions of the research is to understand why - by what means - the legacy of earthen architectures built in Armenia is so devalued until today? A. Marouti's thesis defended at the Politecnico di Milano - *Preservation of the architectural heritage of Armenia: a history of its evolution from the perspective of the early 19th century European travelers to the scientific preservation of the soviet period* [3] - is interesting to this point of view, because it brings together a historical panorama of the consideration - and conservation - of architectural heritage in the Republic of Armenia. In contrast, it also makes it possible to note that vernacular productions are still far from being considered as real heritages in contemporary discourses on architecture. On the other hand, his research does not make it possible to construct a global and synthetic representation of these processes of recognition and conservation.

Interests, criticisms of Marouti's thesis on the preservation of Armenian architectural heritages

A. Marouti's thesis covers three periods: starting from the descriptive accounts of the first European travelers until the end of the 19th century, it then shows the awareness of the *identity* of Armenian architecture, at the beginning of the 20th century - within particular the works of N. Marr, T. Toramanyan and J. Strzygowski; to finally describe all the conservation devices of the 20th century during the Soviet period. The choice to start from the accounts of European travelers to understand this taking into account seems relevant to us in several respects. Indeed, often the Armenian elites have been trained in Europe or have been influenced by European education [4]; on the other hand, the European representations of the Caucasus - having served as a basis for their formation - were constructed from an ethnocentric Western culture. Considered by current researchers as linked to the concept of *Orientalism*, this knowledge of the Orient has been strengthened year after year, based on cultural a priori and Manichaean visions, sometimes paradoxical as shown for example by D. Vinson [5].

In section III, A. Marouti concentrates more particularly on a period *between* the travelers' accounts and the well-documented academic studies that will follow, targeting the works of Marr, Toramanyan, and Strzygowski. This is indeed a *pivotal* period in the history of taking into account the Armenian architectural heritage - geographically, culturally, and historically *central*: after the Russo-Ottoman wars (1830), before the Russian revolution of 1917, and the closing of the Soviet Union, and before the 1915 genocide. Thus, between the three empires: Ottoman, Russian and Persian, in the breach of this territory which still allows fairly free movement, people who can exchange studies, research, surveys, meet in Armenia, in the between [6] of both European and Middle Eastern cultures. These views, both inside and outside of Armenia, are valuable and irreplaceable; it will be necessary to wait until the 1970s, in particular with Italian contributions - as A. Marouti underlines in section IV [3, p.174], to find such a fruitful international configuration. Finally, it highlights the importance and impact of J. Strzygowsky's theses on the European scene - thus opening up the scientific debate on the Armenian origins of Romanesque and Gothic architecture in Europe...

On the other hand, other aspects - which we consider equally important - are left in the background by A. Marouti. In Section V, *Awareness and architectural preservation in soviet Armenia*, he notes that S. Vardanyan emphasizes the need for a systematic study of Armenian folk dwellings before they completely disappear: "[…] *architectural theorists in Western countries have limited their studies to monumental, religious and secular buildings and have not addressed the architectural evolution of the homes of ordinary people*" [7, p.6]. However, in 2018, A. Marouti devotes only three pages of section V to this issue of popular architectures - *Attention to folk architecture in soviet Armenia* - and two other pages in Section I. By thus putting popular legacies in the background, he continues, in fact, consciously or not, the Western travelers' attitude denounced by S. Vardanyan as early as the 1930s.

A paradoxical presupposition

In the chapter, *The architecture of village house,* concerning the analysis of travelers' accounts, A. Marouti speaks in pejorative terms of "*low-quality materials*" [3, pp. 33, 37]; while he quotes some travelers who had already spotted in these architectures and these materials, which currently constitute the qualities and assets of sustainable development: local bio sourced materials, with interesting thermal inertia and therefore more economical [8]… He understands well that the popular habitats are in poor condition due to lack of maintenance because Armenia has been for centuries the territory of wars between three great Empires – Ottoman, Persians and Russians [3, pp. 37, 87].

But, he takes sides with the stone material - is it because it is a *habitus?* - and it is *agreed* to think - implicitly - that it is a more solid and therefore more durable material; "*Despite the abundance of stone, the basic construction material was earth and mud for the walls and timber for the roofs*" [3, pp. 34, 93]. However, this question is not addressed - and yet deserves to be asked again: why this choice to build with earth when there was the presence of the stone resource ("*stones were reserved for water features and paving streets*" reports S. Vardanyan in his study of popular architectures [7])? The last part of A. Marouti's thesis is entirely devoted to the conservation processes of the Soviet era and mainly talks about monuments.

In his research - the title of which is, let us recall, *Preservation of the architectural heritage of Armenia* - does A. Marouti *implicitly* side with architects who consider *ordinary constructions* as not (yet) being *architectures having value*? At no time does he specify that he will only develop the "scholarly architecture" component. His research finally provides little information on the processes of preservation of popular constructions in Armenia: certainly, because during the Soviet era and until now, there has been very little conservation of these modest architectures - already because of a vast corpus of monuments to be restored - but also probably due to the low esteem that the author attributes to them...

Today, this pushing into the background of Armenian domestic architecture (*ordinary*) and the implicit refusal to recognize it also as a valuable *legacy* - to become *heritage* - is all the more problematic as other architects or historians, such as R. Aghababyan [9] or V. Haroutounyan [10], for example - following Vardanyan - underlined their importance by showing the relationship between the traditional *glkhatun* house (*Glkhatun/ Գլխատուն: glukh/ գլուխ* - head, and *tun/ տուն* - house [11]) and domes of monumental Armenian buildings, religious (churches, monasteries) or lay (palace).

This filiation should therefore be reconsidered with regard to the theses of T. Toramanyan [12] and J. Strzygowski [13] who undertook to show that Armenian architecture is at the origin of Romanesque and Gothic architecture in Europe. Even though these assumptions are still sometimes discussed today, to continue the reasoning on the filiation "traditional house-Armenian religious heritage" would mean that the popular Armenian house *glkhatun* can constitute one of the origins of monumental European religious architectures too...

Reconsidering popular constructions, a renewed line of research in Armenia

Most of the research that puts popular legacies in the background – because they are considered *ordinary*, minor, or fragile and unsustainable, associated with poverty, etc. - in fact, ignores 90% of constructions! G. Casnati's lecture taken from the *Heritage on Earth* symposium in Yerevan in 2015 perfectly describes the current Armenian situation:

> *For various reasons, it is above all the medieval religious architectural heritage that has been brought to the attention of researchers and tourists who, each year, more numerous, visit Armenia. The rich archaeological heritage, the remains of the fortresses, the works of vernacular and modern architecture are still very little considered and neither preserved nor valued. When they are of high quality and present particular, interesting, and singular aspects, they should be objects of study and, if properly highlighted, could play a very important role in the development of tourism. Unfortunately, their value is still unknown […]. The raw earth constructions, of which we find in Armenia some examples of almost all ages are abandoned or destroyed either because of the difficulty of the restoration or because of the low value attributed [14].*

There is therefore still a lot of work to be done to collect, complete, make known this *corpus of ordinary constructions*…, in Armenia and in the neighboring countries: on the ground, for what still exists, and through books. This is what architects devoted themselves to very early on – Vardanyan then H. Khalpakhchyan [15] or N. Papukhyan [16], etc. It is with a similar intention that our research undertook to raise awareness of earthen constructions to transform this view of *popular architecture*. In the next part, we propose to establish and trace the evolution of this awareness in Armenia - its actors, their interactions - starting from the travelers' accounts.

2. Emergence of the notion of vernacular in Armenia and method of putting in *vis-à-vis* with timelines

Emergence of the notion of vernacular architecture and methodology

At first, we will follow the same strategy as A. Marouti, by selecting what concerns this *other corpus* - what is now called *vernacular architecture*. We will trace the evolution of its consideration in the specific case of Armenia, in order to highlight the different actors in the progress of research to better understand their disciplinary affiliations, their interactions, but also the evolution of ideas, of their objectives, to show the awareness of the issues measured by these different actors. Our approach will therefore seek to show why, when, and how certain Armenian architects or historians favored *ordinary constructions* and through what type of commitment: notably with studies and surveys, but also militant texts. These commitments are certainly consistent with the values and ideology of the Soviet period for the special attention and valorization of the popular, the ordinary.

But as we have seen, the influences were wider, European and even Western. It is therefore necessary to situate this local Armenian context in the general context of the evolution of these ideas in the West - Europe / USA to be able to evaluate and show to what extent certain Armenian architects understood the importance of popular constructions relatively early on and at the same time to observe that these avant-garde approaches are - if not forgotten, at least - currently hidden.

The objective is therefore to represent the international panorama of the emergence of this awareness by identifying, first of all, the pioneers who contributed to the establishment of the problem of the vernacular. We will then discuss the birth and establishment of the semantic field because vocabularies vary according to points of view and cultures. We will end by showing the involvement of international bodies and public institutions for the protection of these heritages.

Commitments for the popular, for what issues?

It is easy to understand that the reasons for which this particular interest in *ordinary architectures* has developed have evolved over time. But it is necessary to clearly distinguish between the various repercussions and therefore to measure the importance of the consequences of these awareness-raisings. This lucidity on the different categories of issues will thus be a decisive criterion for reporting on these developments. For example, the historical curiosity of the first American antiquarians - who began by studying certain objects as indicative legacies of particular cultures - cannot be put on the same level as a conservation strategy for samples of remarkable constructions - in order to turn into *heritage*[3]; or at the same level as a *militant commitment* to better reveal the *origins* of architecture. In Armenia in particular, for some architects, popular and modest constructions make it possible to understand the evolution - the DNA - the *germ* of monumental architectures [7, p.6] whereas today a current user will only have esteem for *modern* constructions, as O. Aurenche observes [17].

Finally, reconsidering the vernacular as a *resource* for future architectural and landscape developments is yet another step in this process (Fig. 2).

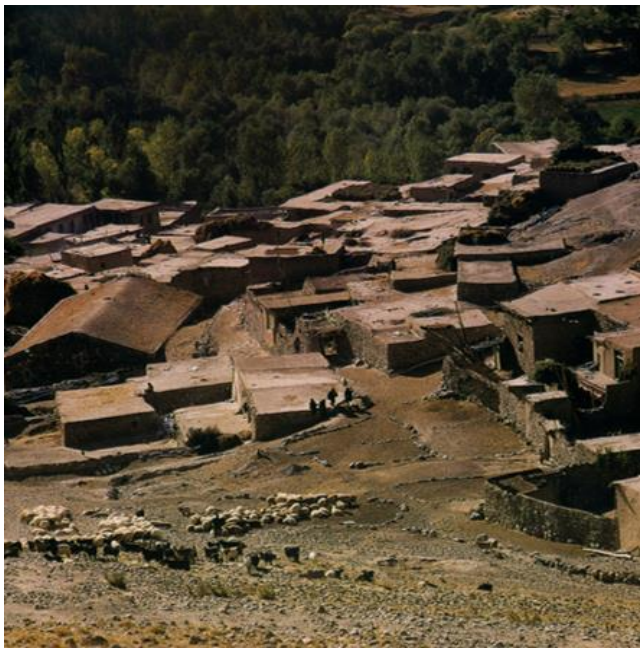

Fig. 2. *Local resources form the vernacular landscapes characteristic of their cultures: Village Muzhumbar, 17th c. (now Iran), cf. "Documenti di Architettura Armena" collection, Politecnico di Milano, n° 20 (Sorhul)*

[3] V. Veschambre, Le processus de patrimonialisation: revalorisation, appropriation et marquage de l'espace. Les Cafés géographiques, 2007. *http://cafe-geo.net/wp-content/uploads/processus-patrimonialisation.pdf* Patrimoine et patrimonialisation, de l'objet à la relation, 2015. *http://cafe-geo.net/patrimoine-et-patrimonialisation-de-lobjet-a-la-relation/*

This was the theme of the last ICOMOS CIAV & ISCEAH symposium in Pingyao (China) in 2019: revitalizing territories based on material and immaterial cultures, landscapes, know-how, resources, social dynamics [1]…

We pursue the reasoning even further by recognizing vernacular productions as a real *resource* (lesson) for innovation[4]. For some, this is even becoming a global issue and the only hope for fostering a dialogue of cultures and fighting against the impoverishment due to globalization, as argued by F. Jullien in *Le pont des singes* [18].

References and graphical representation tool

For the part concerning Armenian architecture, A. Marouti's work remains the main reference used in this article (even if it essentially targets monumental buildings), because it also mentions the important testimonies on popular constructions. For the western part, we will also rely on M.-F. Bisson's research who questions as follows: *can ordinary modern architectures be considered vernacular* [19]? Even if its objective is different, its study shows how slowly this attention in favor of the vernacular was built, in successive stages, particularly in two territories: French and Anglo-Saxon.

To visually synthesize these different historical data and to contextualize the development of this awareness, we propose to bring together the salient events by means of *timelines*. Two facing friezes - Armenia/West - highlight the interrelationships *between* these two cultures. This open tool - because it can be supplemented at any time - constitutes a sort of library that allows for research to be established, with interdisciplinary contributions [20]. Finally, their modular design allows certain events or processes to be graphically characterized as a posteriori. The chosen tool is free French software *Frisechrono*, used in particular by teachers[5].

Graphic codes of timelines (Figures 3, 4).

The first timeline (Fig. 3) concerning Armenia itself presents a setting in vis-à-vis two types of information:

- Below the time scale:
  - The periods of wars - culminating in a peace treaty - are marked by bands of different colors: Persians against Ottomans in *pink*; Russians versus Persians in *orange*.
  - Iranian occupation is in *dark blue*, Ottoman occupation in *olive green*, Russian occupation in *light blue*. Note that the occupations of Armenian territory by Russia in the 19th provide a better understanding of the increase in European travelers to Armenia.
- Above the time scale are gathered the various publications, read by Armenian intellectuals:
  - The accounts of European travelers concerning Armenia (thumbnail with image: French travelers are in *red*; English - in *blue-green*; German - in *sky blue*).
  - Then follow (in *green*) the 3 key authors - Marr, Strzygowski, Toramanyan, - they initiate the consideration of the Armenian architectural heritage and have theorized the contributions of Armenian architecture to European architecture.
  - And finally (in *purple*) - from the beginning of the 20th century - the Armenian authors of the Soviet period: these are the pioneers, who, by producing field studies, draw attention to *popular architecture*, to introduce the *vernacular* and make it known, by showing its richness and its qualities.

Why do we place Western travelers on the timeline that concerns Armenia? Their talk is that of Westerners speaking to Westerners, but they have been read and have influenced Armenian and Russian intellectuals. Above all, they travelled to Armenia and tell about Armenia, these are the stories of travelers only; then they are followed by Marr, Strzygowski, and Toramanyan who theorized from and on Armenian architecture.

[4] http://www.vegetal-e.com/fr/technique-vernaculaire-pour-architecture-innovante_218.html.
[5] http://frisechronos.fr/

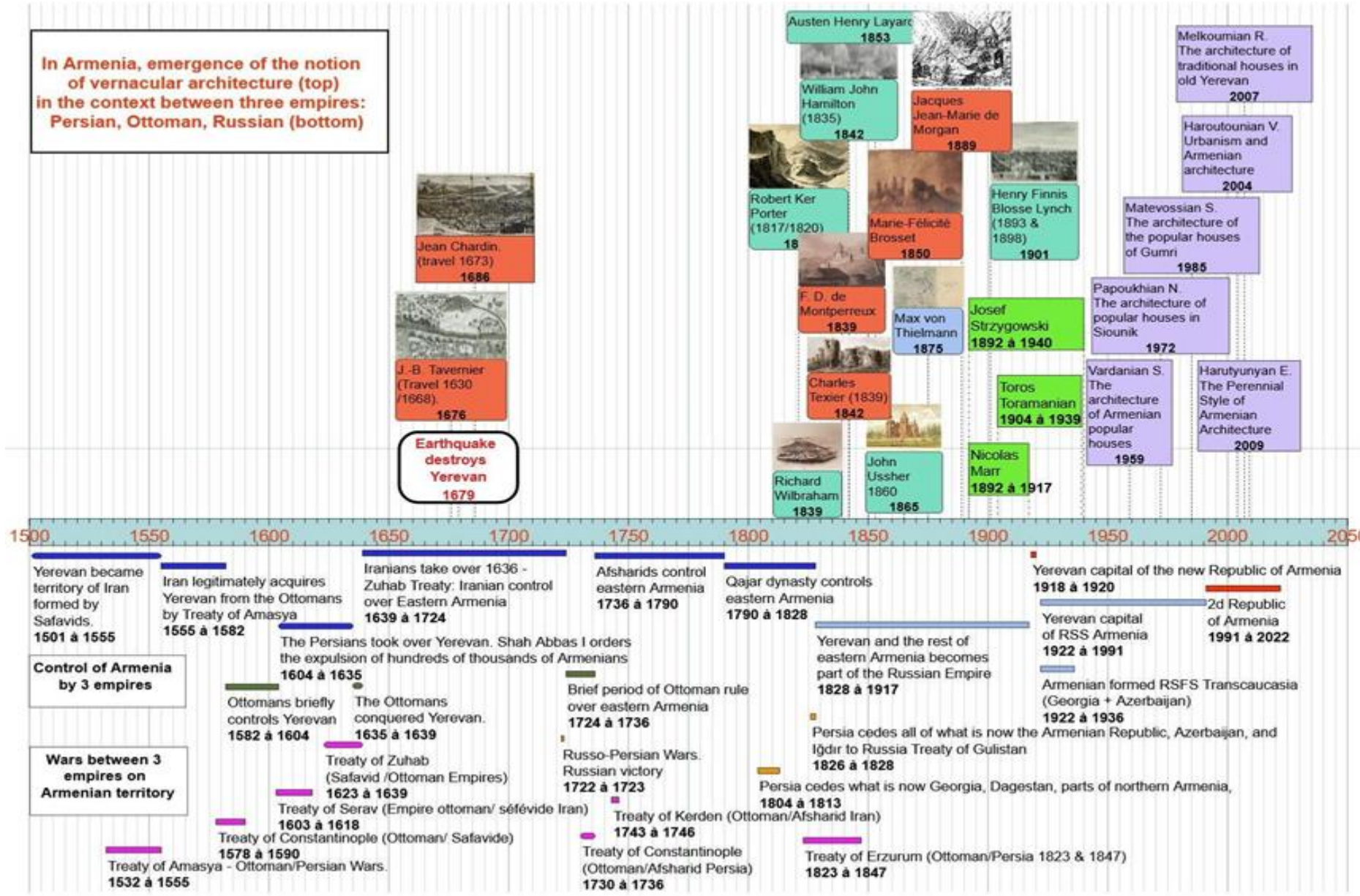

Fig. 3. *In Arménia, emergence of the notion of vernacular architecture (top) in the context between three empires: Persian, Ottoman, Russian (bottom)*

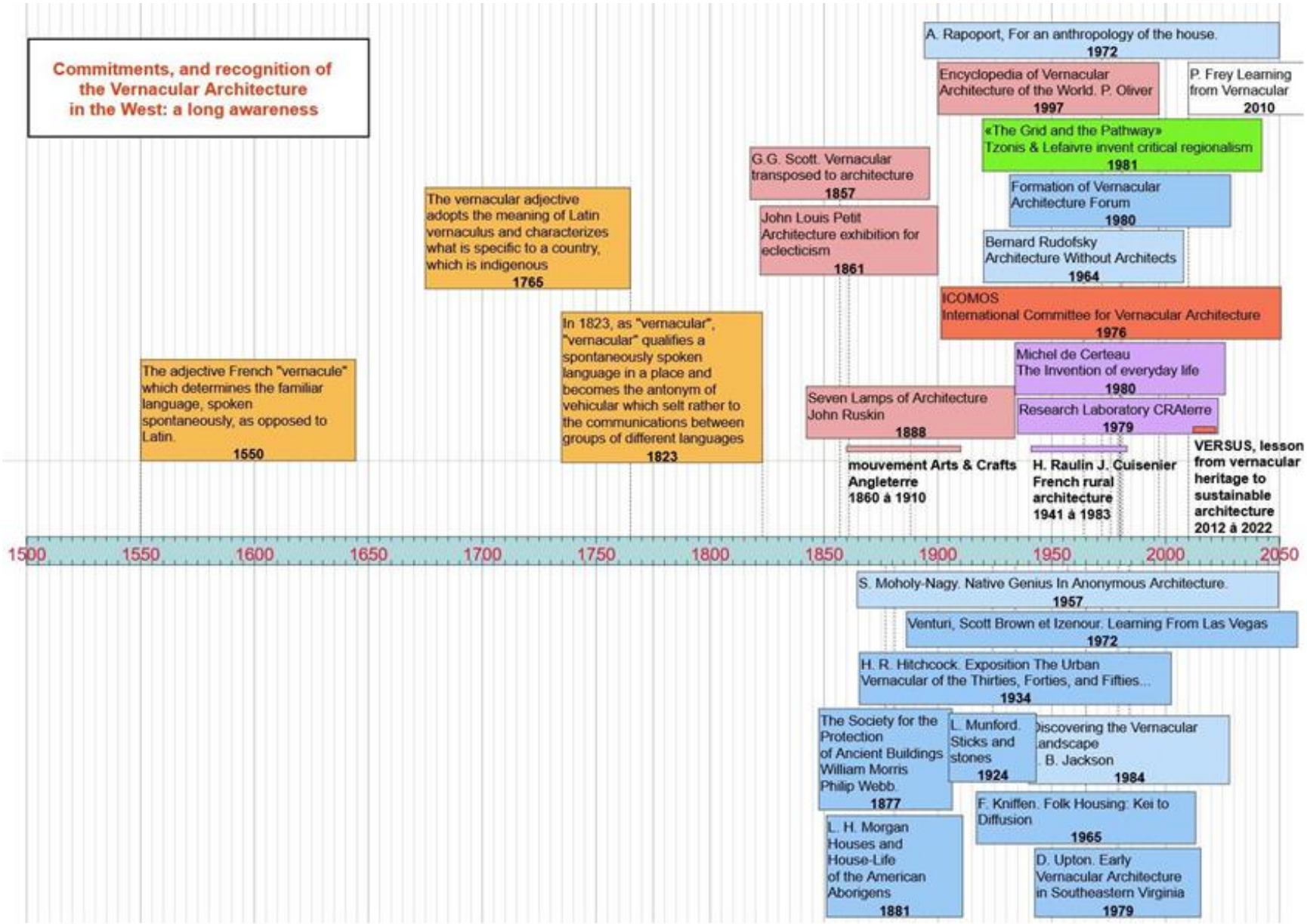

Fig. 4. Commitments and recognition of Vernacular Architecture in the West: a long awareness

3. Recent interest in the vernacular in the West

For the Western part, the timeline (Fig. 4) separates the Europeans (at the top of the time scale) and the US (at the bottom). We will distinguish with different colors: French in *purple*, Anglo-Saxon in *pink*, American in *blue* (*light blue* for foreigners residing in the US), Greek in *green*, and Swiss in *white*. Two significant events in red: creation of ICOMOS CIAV (1976) and ISCEAH (1987) and the VERSUS project. The Russians' contributions to this theme of the vernacular remain to be studied.

Western - Anglo-Saxon context: the emergence of the concept of "vernacular"

M.-F. Bisson's research brings together the salient events of this awareness and also shows all the interplay of actors, in interaction with the *culture* of the different periods and their influences. It is not possible to report on them here in an exhaustive manner: we have selected the notable advances.

The *vernacular* word was not used for architecture until 1857, first in England: for the first time in the Oxford dictionary by the Englishman G.G. Scott [21] who contrasted it with monumental. Previously - as early as 1823 in France - the *vernacular* term was already used, but mainly for language (as opposed to *vehicular* language). As early as 1861, during an exhibition, the Reverend J.L. Petit (Fig. 5) campaigned for *eclecticism* in architecture - understood as the marriage of the *monumental* and the *vernacular* - taking up the principles (and not only the look as for the *neo-Gothic*) of houses built by ordinary men (medieval constructions) as the basis of the architecture: "*the harmony of a building stemming […] from the designer's respect for the community, the place, and the available materials*"! Architecture is therefore "*no longer just a matter of temples and churches* [but] *must embrace all genres, including domestic architecture*" [22].

Fig. 5. *Reverend J. L. Petit, in the 1860s. http://revpetit.com/*

Then, the *Art and Craft* movement - still in England - militates for a return to *traditional* architecture (in particular Ruskin 1888 [23]), which can be understood - as a reaction - in the country where the beginnings of modern, industrial society and globalization were born. But, it is also a lot in the USA that architects are beginning to take an interest in *domestic* - *folk* - dwellings, probably also because it is a new country that is being built without really having roots and its own history. Upton's synthesis work on this subject (1979) [24] is a privileged reference, let us retain some important previous events: Morgan published *Houses and House-Life of the American Aborigens* in 1881; Morris and Web founded the *Society for the Protection of Ancient Buildings* in 1877; and the historian Hitchcoch organized an exhibition on the vernacular in 1934, etc.

Commitments and recognition of the "vernacular" in architecture

It was really in 1957 that a woman - Sibyl Moholy-Nagy (Fig. 6), of Hungarian origin but of German nationality, all her family emigrated to London in 1935 then to the United States in 1937, due to the rise of Nazism - art and architecture historian, recognizes the value of *vernacular production* as more essential than what is usually considered *architecture*, in a seminal and manifest work, *Native Genius in Anonymous Architecture* [25] .

It is not insignificant that it is a woman who militates for this commitment for a return to *domestic* foundations - local materials and knowledge, location according to the site, creation of a private space... - and for the development of an anonymous daily life! It is also revealing that in 2019, the Wikipedia article dedicated to her only existed in two languages, German and English. Although she offers a - premonitory -

approach to architecture that respects the environment according to current criteria, it is not Sibyl who will be truly recognized (!); it is the Austrian-American B. Rudofsky who will make an impression and who will be remembered: with the exhibition at the MoMA in New York and the eponymous book *Architecture without architect* [26] in 1964!

It is only from these dates that we can consider these Western commitments comparable to that of Armenian architects - including S.Vardanyan (Fig. 7), in Soviet Armenia, who, already a few decades earlier, was already carrying out surveys in the Armenian countryside and was reconsidering vernacular constructions by campaigning for them to be recognized as true architecture. We will come back to this avant-garde figure in the conclusion.

Fig. 6. *Sibylle Sibyl Moholy-Nagy (born Pietzsch) in 1927. Wikipedia*

Because it will be necessary to wait a few more years for more precise publications to structure this interest in the *domestic* and the *ordinary* [27, 28]. Indeed, it was not until 1976 that ICOMOS formed a section *Commission For Vernacular Architecture, CIAV*[6] and in 1997 a British Paul Oliver published the first encyclopedia of the vernacular in the world, in 3 volumes [29]. We should also point out that in France - with the favorable role played by rural anthropologists and geographers in the middle of the 20th century - there is a collection on French rural architecture classified by region, complete and of great interest: it was published in 1964, following multidisciplinary research and surveys carried out from 1941 to 1948 [30].

The vernacular as a resource

If we can consider that in the United States, S. Moholy-Nagy already understood the vernacular as a *resource*, in Europe, in this perspective, a second important step was taken with an article published in 1981 by two Greek teachers. In *The grid and the path* [31], A. Tzonis and L. Lefaivre put forward the founding notion of *Critical Regionalism*. It is this concept that will inspire K. Frampton's essay in 1983 - *Towards a Critical Regionalism: Six points of architecture of resistance* [32]. *Critical regionalism* is not simply *regionalism* [33] which takes up - by imitating - the forms of the past; but an approach to architecture which above all takes up the principles of the vernacular and thus makes it possible to establish a creative mediation between the two styles of architecture: on the one hand modern, contemporary and international; on the other local and traditional.

Finally, it should be noted that the current French laboratory CRAterre (Research center intended to promote raw earth architecture in the world and created in 1979) participated in the *VERSUS* research project [34], led by five European laboratories: Italian, Spanish, Belgian, Portuguese and French. This project proposes a qualitative analysis grid that makes it possible to evaluate a contemporary construction from 15 criteria and to see to what extent a contemporary architecture meets the environmental, socio-economic requirements, etc., according to the "model" of local traditional architectures - *vernacular*. But we can also consider this evaluation tool as a lever for innovation if only by the richness of the debates it generates within the design groups. In 2014, with *VERSUS*, an additional step was taken in this reconsideration of the vernacular and its recognition as a real resource for the sustainable development of human settlements.

The culmination of a long awareness: the vernacular landscape

Thus, from the 1980s, there are many more publications on the vernacular: it has become almost a must, even if differences in definitions and meaning of the word still remain between *ordinary*, *domestic*, *indigenous*, *rural*, *folk*, *local*, *traditional*, *secondary*, etc. [35]. Besides, is an exact definition of the *vernacular* necessary?

[6] C. Machat, The History of CIAV. https://www.icomos.org/publications/vernacular3.pdf

Can we not be satisfied with an indefiniteness of the vernacular as some claim an indefiniteness of architecture [36]?! Nevertheless, there are still a few last steps to mention in order to finish sketching what seems to be the culmination of a slow taking into account the vernacular. A final key contribution is certainly that of the American J. B. Jackson who broadened the notion of vernacular to landscape in 1984, with *Discovering the Vernacular Landscape* [37]. This concept of the *vernacular landscape* makes it possible to understand the interrelation between architectures and their environments - an ecosystem where architecture draws its resources from its environment while transforming it.

Finally, during the last "ICOMOS CIAV and ISCEAH" 2019 symposium in Pingyao, in China, the work of the speakers had all integrated the landscape as an essential element of vernacular human settlement and as a lever for the revitalization of local territories. As the president of ICOMOS-ISCEAH - Mariana Correia - reminded in her introductory lecture, it is a global consideration that is necessary, "*A cultural landscape is remarkable due to associations between, architecture, people and landscape*" [38]. We are currently moving towards an understanding and a global consideration of local cultures understood as *ecosystems*, where the different components of life are balanced in harmony with a *milieu* – a *fûdo* in the sense of the Japanese philosopher T. Watsuji [39] - notion reintroduced in France by A. Berque. This understanding also renews the view of the European travelers' accounts in Armenia, who often spontaneously describe and/or draw human settlements in the landscapes thus built by men over time - such as, for example, the Armenia's irrigation networks described by F. DuBois de Montperreux [40].

Conclusion: S. Vardanyan, already a precursor in Armenia USSR (Fig. 7)

Thanks to this chronological synthesis and with this confrontation between East and West, we can see that taking into account the vernacular is relatively late in Europe. In fact, forms of militant engagement are earlier: first with architects in Armenia, then with a historian in the USA. Our study makes it possible in particular to bring together two geographically and culturally distant researchers: - S. Vardanyan, who published his work on popular architecture in 1959 in the Armenian SSR, but who conducted his work (surveys and interviews) in the field from the 1930s; - and S. Moholy-Nagy who published her work in 1957 and began her research in 1952, thanks to a scholarship granted by the Architectural League of New York [41]. These two *committed* and *militant* paths can be related: both were forced to flee genocide, to acquire a double or even triple culture and their work has remained somewhat in the shadows. They also deserve to be rediscovered and valued.

Fig. 7. *Soghomon Vardanyan, 1950s:born in Erzeroum (Karin in Armenian) present-day Turkey (1903-1970), architect graduated from the Polytechnic School of Yerevan in 1936.*

In Armenia, finally, even if T. Toramanyan punctually brings testimonies on popular know-how (for example for traditional houses and the construction of floors and ceilings in earth and wood [42, 43]); this remains marginal in his work, mainly focused on monumental architecture - which is consistent at the beginning of the 20th century, where Armenian culture is threatened with extinction, particularly following the 1915 genocide. It was therefore S. Vardanyan who first campaigned for *popular architectures* considered ordinary, minor or regional, etc. And he put forward a thesis that can be considered avant-garde: popular architecture is the *germ* of monumental architectures - which, following processes of heritage, are currently recognized: it is their origin and also deserves a revaluation.

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Received: 16.03.2022
Revised: 14.04.2022
Accepted: 21.04.2022

DOI: https://doi.org/10.54338/27382656-2022.2-010

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ANALYSIS OF THE STRUCTURE OF THE DISPERSED GAS PHASE PRODUCED IN TURBULENT FOAM-CONCRETE MIXERS

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It was noted that the overall stability of foam concrete mixtures made by single-stage technology depends significantly on the measure of distribution of the dispersed gas phase involved in the mixing. The effect of the gas phase structure on the foam concrete mixture was evaluated by the value of the current consumed by the concrete mixer. The results of the experimental studies have shown the relevance of the scientific justification of mass transfer phenomena, that occur during mixing of raw materials in an industrial turbulent mixer. It was found that the process of dispersion of large-sized gas inclusions formed in the foam concrete mixture in the initial period of high-speed mixing is characterized by achieving the maximum power consumption at the mixer shaft. Then there is a slight decrease in energy consumption, in which there is an additional distribution of the dispersed gas phase, sufficient to attain stability of the foam concrete mixture.

Keywords: *Disperse gas phase, foam concrete mixture, surfactant, turbulent mixer, energy consumption, foaming agent, mass transfer process.*

Introduction

Turbulent mixers are currently used for the preparation of foamed concrete mixtures by single-stage technology. To achieve the properties required by practice, it is important to make mixtures in such a way that the structure obtained as a result of mixing in the concrete mixer, has aggregative and sedimentation stability during the whole period of its transition “from viscous to solid”, which lasts from 1 to 2.5 hours. According to different data, the following are required for this:

a) The initial raw material’s high dispersion [1,2],
b) Achieving high dispersion of the gas phase involved in the mixture [1,2],
c) Minimum possible content of foaming agent molecules in the liquid phase of the mixture for a given composition (density) [3-6],
d) The minimum possible period of phase transition “from viscous to solid” [7].

This list of factors governing the quality of foam concrete mixtures and cured concrete to date does not have mathematically clearly defined patterns. Therefore, the standards characterizing the requirements of foam concrete allow for the possibility to obtain materials of different densities and strengths from the same raw material composition.

On the one hand, such an approach to the quality of the material reflects the high demand for it in practice. On the other hand, it indicates insufficient scientific understanding of the mass transfer processes governing the structure and properties of gas-filled concrete.

Materials and Methods

The analysis of the list of factors controlling the aggregative stability of the mixtures and the quality of the hardened foam concrete allows us to state that ensuring the required level of dispersity of the raw materials does not need additional justification, and can be set before the preparation of the foam concrete mixture. All other factors are interdependent during the predominance of viscous bonds between the components of the mixture and, therefore, have a difficult to predict and extremely significant impact on the quality of hardened foam concrete.

It is important to understand that if the dispersed gas phase consists of large pores, then after the mixing process is completed, it cannot be fully retained in the structure of the cement-sand mortar (slurry) and the mixture placed in the formwork during the phase transition will partially lose it. This process will inevitably lead to a destruction of the aggregative stability in the foam mixture. It is possible to obtain the following results in hardened foam concrete, depending on its intensity:

- With a small amount of loss of dispersed gas phase, there will be a decrease in mechanical strength with some increase in the average density,
- With a significant loss of the dispersed gas phase, the period of destruction of aggregative stability will be followed by the phenomenon of sedimentation. The solidified material will have not only increased density at reduced strength, but also different values of strength across the thickness of the concrete body.

From the above it follows that obtaining high-strength foam concrete is possible only when the dispersed gas phase has the optimal dispersion for the given composition. Naturally, the question arises about how to fix this moment in practice.

Results and discussion

Theoretical analysis of mass transfer processes in the production of foamed concrete mixtures [7-9] suggests that the moment of reaching the maximum power consumption by the concrete mixer shaft may correspond to the completion of the first phase of air-entrainment. The reason for this established fact is the large size of gas inclusions. The three-phase dispersed system, the macro-homogeneity of which at this stage is ensured only by the capillary bonding forces, will most vigorously resist the movement of the working body of the mixer and, thus, require increased energy consumption.

Practice and our experimental studies show that to achieve the optimal dispersion of the entrained gas phase, it is necessary to continue mixing [6,10]. At this stage of preparation of foam concrete mixture, mass transfer processes will be characterized by the following features:

- The grinding of the previously involved large-sized dispersed gas phase will require an additional transition of the surfactants from the interparticle liquid to the foam films, and as a result of this process, the total surface of the “gas-liquid” phase interface will increase [11, 12],
- In the interparticle liquid of an intensively mixed foam concrete mixture, due to a decrease in the concentration of surfactants in it, the viscosity will naturally increase and, as a result, the capillary bonding forces between all components of a three-phase dispersed system [12].

At this stage of mixing, despite the increase in viscosity in the dispersed system, the energy consumed by the concrete mixer fluctuates and can decrease by 3.5–5.0% compared to the maximum power consumption.

Experimental studies of the above-justified mass transfer processes were carried out in production conditions with a turbulent mixer, equipped with a 30-kW asynchronous (induction) motor and a reducer (regulator valve). During the experiment, the current consumed by the electric motor during the manufacture of the foam concrete mixture was measured. The obtained results of the current required by the electric motor for the homogenization of raw materials are presented in tabular form (Table).

Table. Current required by the electric motor for the homogenization of raw materials

Mixing duration, (s)	0	10	30	60	90	120	150	180	210	240	270	300
Consumed current, (A)	30	30	40	49	54	55	53	52	53	52.5	52	52.5

Taking into account the order of introduction of raw material components into the mixer flask, analysis of the data (Table) shows that:

- At the stage of loading water and the initial quantity of solid components of raw materials into the running concrete mixer (the first 10 seconds), the power consumption of the mixer is almost constant and minimal,

- Continuous loading of water, sand, and Portland cement causes a significant portion of the mixing water to become physically bound, which leads to an increase in the viscosity of the composition, and the energy consumption required for the movement of the mixer's working body increases,
- After half a minute from the beginning of the mixing process, the foaming agent was added to the mixer, and the energy consumption increased up to 2 minutes from the beginning of mixing, due to the air entrainment and more complete transition of mixing water into a physically bound state,
- Further homogenization of the mixture components was occurred at such a level of current consumption, which is characterized by fluctuations of +3.5–5%.

We believe that the character of energy (current) consumption recorded in the experiment is due to the presence of mutually competing mass transfer processes during this period, consisting of:

- Grinding of the initially involved surfactant of the coarse-dispersed gas phase,
- The flow of physically weakly bound water from large foam films into smaller ones,
- Reduction of the residual concentration of surfactant in the inter-particle liquid.

All of the mutually competing features of mass transfer listed above contribute to improving the aggregative stability of foam concrete mixtures and, as a result, should contribute to an increase in the strength of hardened concrete.

Conclusion

The analysis of the features of the involvement and changes in the structure of the dispersed gas phase during the production of foam concrete mixtures in the turbulent mixer showed that the mixing duration is an important tool to ensure the quality of foam concrete mixtures, that is, their aggregative stability. Other things being equal, only the high dispersion of the gas phase contributes to the acquisition of aggregative stability of foam concrete mixtures in the period between the moment of their placement in the formwork and the phase transition "from viscous to elastic". From the performed industrial experimental studies, the effect of the mixing duration of the foam mixture components on the power consumption of the turbulent concrete mixer showed that the first phase of the formation of the dispersed gas phase requires the maximum power consumption. After involvement of the main volume of the coarse-dispersed gas phase, there is a slight decrease in energy consumption, sufficient for its additional dispersion, characterized by fluctuations in the range of 3–5 % of the energy consumption.

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Received: 17.05.2022
Revised: 10.06.2022
Accepted: 13.06.2022

DOI: https://doi.org/10.54338/27382656-2022.2-011

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THE TECHNOLOGICAL ALTERNATIVES FOR ENERGY AND HYDRAULIC IMPROVEMENTS

The problem of converting attenuated hydraulic energy into power energy in an artificial local resistance unit placed on a gravity drinking water pipeline (outlet control valve, pressure regulator) without disrupting the hydraulic regime of the water pipeline is examined. It is recommended to replace the regulator with the same resistance hydraulic turbine, and thus, with its corrective device, automatically adjust the consumption outlet of the water pipe. The energy and economic data of the hydraulic turbine unit to be built on the «Arzakan-Yerevan» drinking water main pipelines have been presented as an example of proposal implementation. According to estimations, the small hydroelectric power plant on the Yerevan water pipeline could produce 90 million kWh of electricity per year. It should be noted that the water supply system in Yerevan has around 300 half-open valves and pressure control devices, and in case of conversion of many of them, it is possible to apply the suggestion given in the article.

Keywords: *hydraulic resistance, attenuated energy, hydraulic turbine, corrector, water pipe, energy efficiency indicator, renewable energy, pressure management.*

Introduction

The traditional non-renewable sources of primary energy with limited resources continue to dominate. The overexploitation of fossil energy brings about severe pollution issues, including air pollution, water resource shortage, soil contamination, and ecosystem degradation [1]. Therein, taking into account the population growth in the country, the continuous increase of household and industrial energy supply, the further quantitative (extensive) development of the energy, which is based on traditional raw materials is inadvisable in Armenia. From the point of view of sustainable development and environment protection, the use of renewable energy resources in the energy balance is becoming essential. Water and energy resources are critical to human survival, and they are constantly under economic, technical, demographic, and societal pressures. Pumping in water supply systems (WSSs) is projected to account for 2–3% of global power usage [2], with motor-pump sets accounting for 80–90% of this demand. It is one of the most significant operational expenditures connected with WSSs [2].

Promotion of the efficient and rational use of water and electricity in WSSs plays a strategic role in the quest for the sustainable development of nations as well as in the mitigation of and adaptation to the causes/consequences of climate change. The high potential for the application of water and electricity rational use actions in WSSs has been attributed to poor infrastructure and operational procedures, particularly in developing countries. Moreover, according to the Millennium Development Goals (MDGs) [3], there is a need for more sustainable alternatives in the expansion and implementation of new systems by the year 2015, further, according to the MDGs, there is a target to halve the proportion of people without sustainable access to safe water and basic sanitation. Small hydroelectric power stations (SHPS) should be recommended as a renewable energy source for domestic drinking water and water delivery networks in the places where the local hydraulic resistances, half-open valves, or pressure regulators are available. Simultaneous use of the above-mentioned systems is economically feasible for electrical energy production and water delivery, and in principle, is an example of total water resource usage [4]. Although in past decades the use of hydropower was one of the main sources of energy, today the vector of action has changed, the sector is viewed as a direct

consumer of electricity, which affects the distribution of water resources in the context of energy consumption and use of energy [5]. According to Frijns et al. [6], the high consumption of energy affects water industries around the world, been associated with climate change issues. According to Dias [7], the rational use of energy aims to provide sustainable development through the correct use of energy resources at all stages of conversion.

Hydropower recovery. The hydropower potential of water supply systems has been known for a long time, however, it has not been adequately explored worldwide. Cases of micro turbines used for power generation in water supply systems have been reported in the literature (e.g., [6]). Systems installed in areas with high topographic gradients, in which water is transported by gravity, tend to offer high pressures in the water mains and distribution networks, making these systems capable of hydroelectric power generation. In addition to generating electricity, turbines installed in water distribution networks can act as pressure control systems, replacing the pressure-reducing valves (PRVs), which are important tools in the management of water losses/leakages [8,9]. While PRVs reduce the pressure through the dissipation of energy, water turbines can convert this excess pressure into useful electricity [9]. The main benefits of hydraulic energy recovery in WWSs, according to Vieira and Ramos, include increases in the energy efficiency of the system through the use of local sources and decreases in the dependence on external /grid energy, additionally, hydraulic energy recovery favors overall reduced operational costs. Vieira and Ramos [10] also emphasize that the implementation of small hydro plants in WSSs presents a considerably reduced implementation cost because many of the necessary components are already present in typical WWSs.

To assess the applicability of the proposal, the possibility of building a SHPP on the Arzakan-Yerevan drinking water pipeline is presented.

Main part

According to Dias [7], the rational use of energy aims to provide sustainable development through the correct use of energy resources at all stages of conversion. Based on the author's description, the efficient use of energy can be systematized into the following six intervention levels.

- Level 1, the elimination of waste: waste elimination is the most evident level of intervention. In the context of water supply, the most emblematic example of intervention level 1 is the elimination of water losses due to leakages.
- Level 2, increasing the efficiency of power-consuming units: this level includes energy efficiency measures aimed at the technological improvement of processes, which involve, for example, the replacement of old motor-pump sets by high efficiency sets.
- Level 3, increasing the efficiency of power generation units: this level aims to adjust and harmonize the energy production units with the energy consumption units, preferably a posteriori with respect to the level 1 and level 2 interventions. In the context of the present work, we can cite the following examples of level 3 interventions in WSSs, such as the use of renewable sources for water pumping and hydropower recovery.
- Level 4, the reuse of natural resources by recycling and reduction of the energy content of products and services: Dias [7] describes level 4 interventions as those related to the recycling and recovery of energy from waste generated in the considered production process as well as the use of technologies and inputs with reduced energy intensities throughout their lifecycles. Although outside the scope of this paper, both waste water recycling and the energy efficiency of wastewater treatment plants are associated with the reuse of resources, which are characteristic of level 4 interventions [12–15]. Attention should be paid to the fact that the reuse and recycling of wastewater are generally considered energy intensive (as described in Section 1), which can mischaracterize these processes as alternative technologies for enabling energy efficiency and conservation. The typical analysis of a WSS energy lifecycle considers the energy intensities of the chemicals used in water treatment in addition to the materials and components of the physical systems (e.g., pipes). Energy analyses considering life cycle assessments of

WSSs are presented, among others, by Lundinand Morisson [16], Filion et al. [17], Racoviceanu et al. [11], and Stokesand Horvath [18].

- Level 5, discussion of the center/periphery relations: in the context of water supply, level 5 interventions can be obtained, for example, through the decentralization of supply and incentives toward the enhanced use and management of local water sources in the form of distributed water infrastructures [19,20]. Physically, the center/periphery relationship influences the energy efficiency of a WSS once the relative position between the water sources, the treatment plants and the consumers influences the amount of energy needed for water transport as well the head losses along the network and water mains. Filion [21], for example, describes the influence of city shape on the energy consumption of water distribution systems. Level 5 interventions are strongly related to urban planning and zoning and can be effectively implemented through proper and optimized system designs. This occurs because the location of natural water sources (e.g., rivers, springs) cannot be changed, and the layout of water mains and the distribution networks depend on the local topography and other types of infrastructure (mainly the streets and roads).
- Level 6, changes in ethical and esthetic paradigms: level 6 involves changes in opinions, consumer choices and consumer behavior and, therefore, represents the most difficult energy efficiency action that can be implemented.

The energy saving impact of each intervention level can be associated with the specific intervention's difficulty and/or cost of deployment. This nonlinear relationship ideally grows and asymptotically tends to the maximum energy saving potential; that is, when applying the above interventions by following the levels in ascending order, the closer the interventions move toward the higher-levels, the greater the difficulty and/or implementation cost become. Further, in this manner, the cumulative energy savings are present in continuously decreasing increments. This model is shown in Fig. 1, in which all levels were denoted with the same dimension for the purpose of illustration because it is very difficult to establish the actual dimensionality of a level. Although in past decades the use of hydropower was the most evident relation between water and energy, today the focus of this relationship has turned to the role of water as a consumer of electricity, which has turned water distribution into an important stage in terms of the consumption and use of energy [5]. According to Frijns et al. [6], the high consumption of energy affects water industries around the world, been associated with climate change issues.

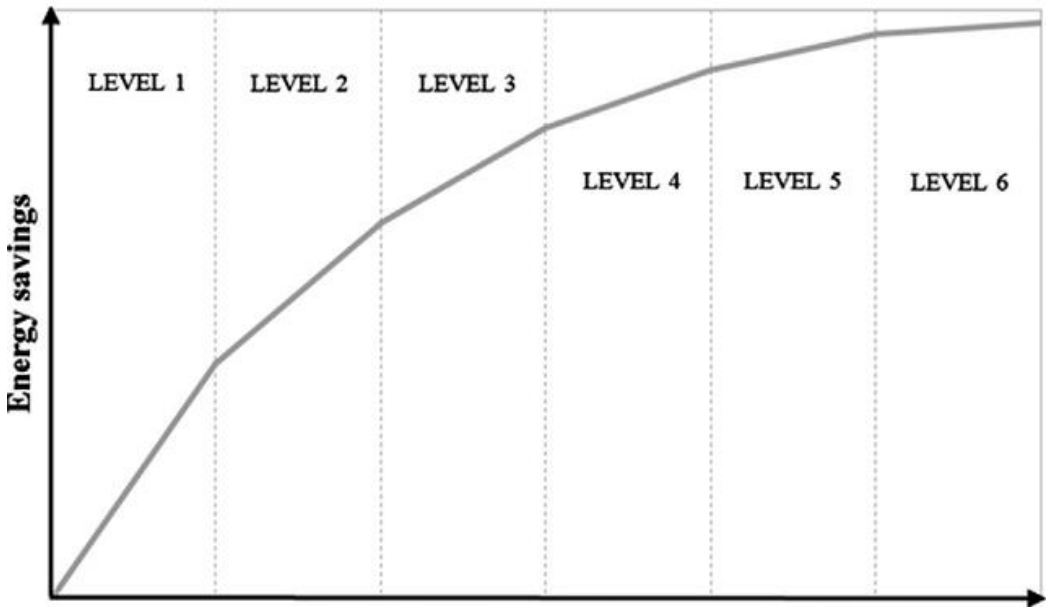

Fig. 1. *The relationship between the energy efficiency intervention level, its cost and difficulty, as well as the cumulative energy savings*

In the paper, we have studied some of the third-level options for improving the efficiency of water supply and drainage systems and energy-economic indicators of the hydraulic turbine unit that will be installed on the "Arzakan-Yerjan" drinking water main pipeline. Many areas of Yerevan (Arabkir, Malatia-Sebastia, Achapnyak, Erebuni villages) and other nearby settlements are served by the «Arzakan-Yerevan» water supply system (Zovuni, Kanakeravan, Nor Hajn, Nor Geghi, Eghvard, etc.). The water supply starts from the Arzakan spring, and in Getamedj administrative region it is separated between two water pipelines with different pressure regimes. On one of the branches supplying the northwestern and western parts of Yerevan city, the development of a SHPP is being proposed. The so-called "compression valve" is currently installed on the considered branch of the water supply system for regulating the volume of water in the dividing junction, as well as to provide the needed water supply pressures in numerous settlements next to Nor Hajn. The valve provides a local hydraulic resistance on the water pipe (the pressure in the water pipe is about 33 meters before the valve, and it is about 13 meters after the valve). The proposed solution is to use a SHPP instead of a "pressing valve" to avoid disrupting the water pipeline's main hydraulic regimes. The site plan created by the Google Earth program is presented below in Fig. 2, and the actual pressure values of the continuous pressure recorders registered by the loggers are presented in Table 1.

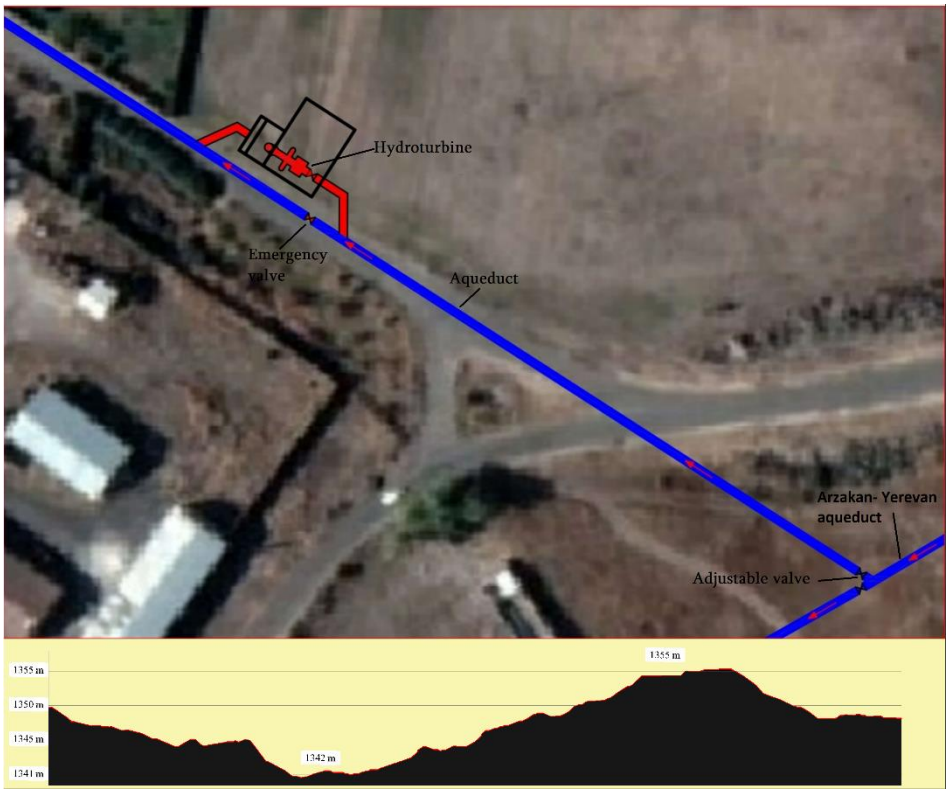

Fig. 2. *The site plan created by the Google Earth program*

The proposal aims to convert the attenuated hydraulic power into electrical energy in an artificially created local resistance unit. There are favorable conditions to use the energy potential for complex purposes at the SHPP construction site (on the branch of the «Arzakan-Yerevan» drinking water main pipeline). At this junction, the average annual outlet of a turbine water pipeline is 1.15 m^3/sec. An outlet controlling valve is fitted on the water pipeline, with throttling providing the outlet. As a result of this regulation, a pressure difference of 20.3… 21.4 *m* is formed on different sides of the valve (Table 1). The proposed solution solves the problem of efficient utilization of the energy of this water flow. It should be noted that there are many so-called "hidden" places of energy on the drinking water pipelines in the Republic of Armenia, the use of which for electricity generation is justified. In this case, it is recommended to replace the regulator on the water pipeline with the same resistance hydraulic turbine, and thus, with its corrective device, automatically adjust the consumption outlet of the water pipe.

Table 1. Data from pressure loggers installed in the research area

Date of survey	Hour	Recorded pressure, *m*	
		Before the local resistance	After the local resistance
15.09.2020	20:00	32.8	13.0
15.09.2020	21:00	33.2	12.6
15.09.2020	22:00	33.3	13.0
15.09.2020	23:00	33.3	13.0
16.09.2020	00:00	33.5	12.8
16.09.2020	01:00	33.8	12.4
16.09.2020	02:00	33.9	13.2
16.09.2020	03:00	33.9	13.1
16.09.2020	04:00	33.9	13.6
16.09.2020	05:00	33.8	13.3
16.09.2020	06:00	33.8	13.2
16.09.2020	07:00	33.7	12.6
16.09.2020	08:00	33.4	13.0

Table 2 shows the average monthly outlet of water pipelines.

Table 2. Hydraulic turbine unit outlet parameters

Month	Water supply outlet, m^3/sec		
January	1.20	July	1.30
February	1.10	August	1.30
March	1.10	September	1.05
April	1.00	October	1.05
May	1.10	November	1.10
June	1.30	December	1.20

According to the data in Table 1 and Table 2, the SHPP design pressure will be $H = 20m$, and the estimated outlet - $Q = 1.15m^3 / \sec$.

The water flow capacity N_1 in the case of estimated hydraulic parameters will be [6]:

$$N = \rho g Q H = 1000 \cdot 9.81 \cdot 1.15 \cdot 20 = 225632\ w \approx 225Kw.$$

Hydraulic turbine selection options. In the case of low water pressure and a substantial annual fluctuation in the outlet, the following two possibilities for hydraulic turbine class selection are reasonable: a. reactive type and b. active type. At low pressures, reaction turbines are preferable over high-speed turbines (Kaplan). However, this turbine efficiency coefficient is sensitive to changes in the outlet. Among the active type turbines, for the given pressure front, preference is given to the Osberger type low-speed turbine (Banki), where the efficiency coefficient is practically unchanged, regardless of the change in outlet. The basic structure of the Banki-type turbine provides an advantage in terms of turbine procurement, cost, and ease of operation. It should be noted that the country has experience in the construction and operation of such low-power turbines. However, there is one criterion to consider: the surplus pressure at the exit of the "Banki" type turbine is zero. As a result, it will only be applicable on the pressure front, where after the turbine installation, the exceed in

water pipe endpoints will provide accounting outlet in gravity mode. The turbine must be placed near the pressure reduction chamber of the water pipe. It means that using an active type turbine in a water pipeline is excluded.

The pressure levels, the outlet flow rates, and the above criteria should be considered when selecting a turbine for each pipeline unit.

It is necessary to include a hydraulic unit in the pressure front, which will perform the regulating valve function, that is, to ensure a consistent drop in the pressure. On the other hand, hydraulic turbine aggregate operating in the united electrical network, must be regulated according to network requirements, i.e., it must have an opportunity to change the water output.

In the case of low pressure, an axial (Kaplan) or double-regulated adjustable-blade turbines are used. In the case of low water flow capacity, such as drinking water gravity pipelines, it is advisable to use an axial turbine with an adjusting apparatus. The hydraulic turbine aggregate must be installed on a pipe bypassing the regulating valve, with turbine inlet and outlet mounting valves.

The adjusting apparatus of the hydraulic turbine and the hydraulic resistance of the pipe bypassing the regulating valve are used to ensure the required pressure drop.

The regulating valve is closed during the SHPP operation, as can be seen.

It is recommended to install the turbine on a pipe that runs parallel to the water pipe, ensuring that the water pipe continues to operate even in case of station failure. Pressure sensors will be installed at the turbine intake and outlet sites to monitor the SHPP's operation. It will deliver the required pressure from the station following the water supply company's regulations. At the same time, the station must be installed on the drinking water supply system, therefore the equipment and the project must meet specific standards[1,2] [22], such as avoiding contamination of the water with lubricating oils and other materials. A water supply system is a set of structures, facilities, and services that produces and distributes water to consumers the distributed water must be compatible with the needs associated with the domestic consumption, utilities, and other industrial consumption in both quantity and quality.

Energy indicators of SHPP. For the elements of a hydraulic turbine unit, let's consider the following average values for efficiency coefficients: $\eta_m = 0.86$ and $\eta_{gen} = 0.94$.

The power on the turbine shaft will be:

$$N_m = \eta_m \quad N = 0.86 \cdot 225 = 193.5\ kW,$$

and at the generator outlet:

$$N_{gen} = \eta_{gen} \quad N_m = 0.94 \cdot 193.5 = 184\ kW.$$

In Table 3, the average capacity of the SHPP and the corresponding average monthly electricity outlet are presented.

It should be noted, that the use of SHPP turbine at a negative outlet height (in our example $h_S = -13m$), in our opinion, is proposed for the first time in world practice. In this case, on the one hand, the occurrence of cavitation is excluded [22, 23], which is a positive factor, and on the other hand, the effect of high-pressure drop on the efficiency coefficient on the turbine exit is unknown, so, in our calculation understated indicators were applied.

[1] Sanitarakan Kanonner yev Normer N2-III-A2-1, Khmelu jur: Jramatakararman kentronats'vats hamakargeri jri vorakin nerkayats'vogh higiyenik pahanjner, Voraki hskoghut'yun, Yerevan, 2002, p. 11 (in Armenian).

[2] Sanitarakan Kanonner yev Normer N2-III-A2-2, Khmelu nshanakut'yan jrmughineri yev jramatakararman ardyunk'neri sanitarakan pahpanut'yan gotiner, Yerevan, 2002, p.14 (in Armenian).

Table 3. SHPP capacities and outlet per month

Month	Capacity, *kW*	Outlet, *kWh*
January	190	141360
February	174	116930
March	174	129456
April	158	113760
May	174	113456
June	206	148320
July	206	153264
August	206	153264
September	166	119520
October	166	123504
November	174	125280
December	190	141360
	Total	1.573.474

Financial analysis

As a power plant with a guarantee of purchasing electricity, the electricity produced by the SHPP (Table 3) is planned to provide to the general energy system of the Republic of Armenia at prices regulated by the Public Services Regulatory Commission[3].

Table 4 summarizes the main financial indicators, based on the expenses of SHPP construction and continuous operation, as well as the provisions of the current legislation of the Republic of Armenia[4].

Table 4. Cost-effectiveness indicators

Names of indicators	U/M	Indicator
IRR (Internal Rate of Return)	percent	10.4
PB (Payback Period)	year	9.0

Conclusion

Based on the approaches presented in the article, it can be confirmed that the inclusion of renewable energy resources in the energy balance is becoming the imperative of the period. In terms of the peculiarities of the mountainous relief of the territory of the Republic of Armenia, to regulate the pressures in the water supply system intended for drinking and economic needs, measures for creating local resistance are often carried out by the water supply organization using half-open valves or pressure control equipment. Equipping these units with a specially designed hydraulic turbine with the same hydraulic resistance and automatic operation through the corrective device will allow the conversion of attenuated mechanical energy into electricity production during artificially created local resistance. It should be noted that Yerevan water supply system has over 300 half-open valves and pressure control devices, and in case of conversion of many of them, it is possible to apply the suggestion given in the article.

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Received: 27.03.2022
Revised: 05.04.2022
Accepted: 16.05.2022

DOI: https://doi.org/10.54338/27382656-2022.2-012

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AUTOMATED REAL ESTATE VALUATION WITH MACHINE LEARNING: A CASE STUDY ON APARTMENT SALES IN YEREVAN

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Real estate is one of the major sectors of the Armenian economy and has been developing dynamically since Armenia transitions from planned to market economies in early 1990s. More recently, large online platforms have been developed in Armenia to advertise real estate offerings, thus reducing information asymmetry, and increasing liquidity in both sales and rental markets. Simultaneously, granular geospatial data became increasingly affordable via platforms such as OpenStreetMap, Google Maps and Yandex Maps. With granular data concerning a representative portion of the real estate offering available online, it is increasingly tenable to monitor the real estate market in real time and develop analytical tools that can automatically and accurately estimate the value of real estate assets based on their internal and external features. This paper sets out to analyze Armenia real estate market and assess the performance of a special class of machine learning models while predicting the price of a square meter of apartments in Yerevan. Furthermore, it is presented the way to determine the most decisive factors which have an influence on the price of apartments on sale.

Keywords: *Real-estate market, machine learning, automatic valuation, feature importance calculation, XGBoost.*

Introduction

Real estate is a major sector in the Armenian accompany. As of 2020, it has a market capitalization of nearly 1 billion USD, and outstanding mortgage loans amounting to approximately 226 billion AMD [1,2]. While the rate of growth of total economic activity fell to 4.4% during the first three quarters of 2021, the same indicator for the real estate market rose to exceed 16% . Economists largely attribute the increasing activity in this sector with the relative lack of alternative investment opportunities, an issue that is exacerbated by the COVID pandemic and the conflict in Ukraine [3].

Increasing transaction volumes and price volatility are the primary motivation for building a holistic, scalable automatic valuation framework. A highly accurate and scalable framework for automatic valuation can help stakeholders in the real estate sector detect potential market opportunities in real time and reduce overhead cost by automating significant portions of the valuation workflow. Furthermore, automated valuation reduces the likelihood of human error or malfeasance negatively impacting the valuation process [4]. The goal of this paper is to analyze the real estate market in Armenia and implement an apartment price prediction model. We will assess the performance of two different classes of tree – based machine learning ensembles, named XGBoost and Random Forests [5,6]. Related works show that these two classes exceed the performance of other classical machine learning models [7]. Furthermore, their primary advantage over neural networks, which often match them in accuracy, is that their hyperparameters are more easily tunable and model performance is more explainable. These factors are especially important for application in banking, since automatic valuation that is used in mortgage loan must be explainable [8]. As an end point of our work we have adopted SHAP (SHapley Additive exPlanations) approach to interpret model predictions and calculate features importance [9].

Data

Data concerning conventional apartment features is collected from the platforms presented in Table 1. These platforms host the largest numbers of real estate offerings relative to any other in Armenia where list.am is the overwhelming leader. It is important to note that these numbers were determined following detailed

deduplication – the process whereby multiple announcements for the same apartment are detected and discarded. Table 2 describes the data gathered from these platforms. This set of features is a distilled version of all the data scraped from the platform, since some of the data was lacking veracity and was too sparse to be used as features in a dataset.

In addition to the conventional data recovered from the abovementioned sources, data concerning the geospatial features of the neighborhood surrounding the apartment was recovered using the *OpenStreetMap* API [10]. A neighborhood is defined as the set of points that can be reached in seven minutes if travelling at the average walking speed via paths designated for walking (such as sidewalks, etc.) and neighborhood isochrones are calculated using the openrouteservice API [11]. Neighborhood features are grouped into the categories described in Table 3. The number of each of these features in the neighborhood immediately surrounding a particular apartment is likely to influence the price of said apartment. In his paper entitled Interpretable Machine Learning for Real Estate Market Analysis, Felix Lorenz applied a hedonic pricing approach to automatic valuation which indicated that distance from the city center and density of neighboring amenities had a positive impact on rent prices [12].

Table 1. The number of announcements in each portal

Platform	Number of Apartments Scraped
Myrealty.am	3834
Real-estate.am	5217
List.am	39062

Table 2. Data types

Variable	Variable Type
Latitude and Longitude	Float
Number of rooms	Integer
Number of bathrooms	Integer
Building type	Categorical
Ceiling Height	Float
Condition	Categorical
Floor/Total Floors	Integer
New Construction	Categorical
District	Categorical
European Window	Bool
Furnished	Bool
Sunny	Bool
Home Area	Integer
Balcony	Bool
Price	Integer

Table 3. Neighborhood feature categories

Category	Examples
Sustenance	restaurants, cafes, bars, clubs, etc.
Education	schools, universities, kindergartens, etc.
Transportation	bus stops, parking lots, charging stations, etc.
Financial	banks, ATMs, currency exchanges, etc.
Healthcare	pharmacies, hospitals, clinics, etc.
Entertainment, Art & Culture	movie theater's, museums, conceit halls, etc.
Public Service	courthouse, post office, town hall. etc.

Data exploration

Fig. 1 illustrates the distribution of the price of a square meter in a Yerevan apartment based on data scraped from the abovementioned sources. This is the target variable that we aim to predict. The histogram peaks around the 800 USD to 1200 USD price category and declines in reverse proportion to price, as expected. It is important to note that the prices quoted in online announcements are often not the final transaction value of the apartments. In fact, our analysis of data reported in the annual report by the Cadastre Committee of the Republic of Armenia indicates that online prices are 1.3-1.9 times higher than those reported by Cadastre, where the coefficient fluctuates based on the administrative district. One issue that is raised because of this distribution shape, is that there is relatively less data to represent apartments on the higher end of the market, therefore leading to relatively inaccurate results on the higher price range. Finally, online prices are often

quoted irrationally, and based on the whim of the seller or agent representative, who may have sentimental value and inadequate understanding of market conditions.

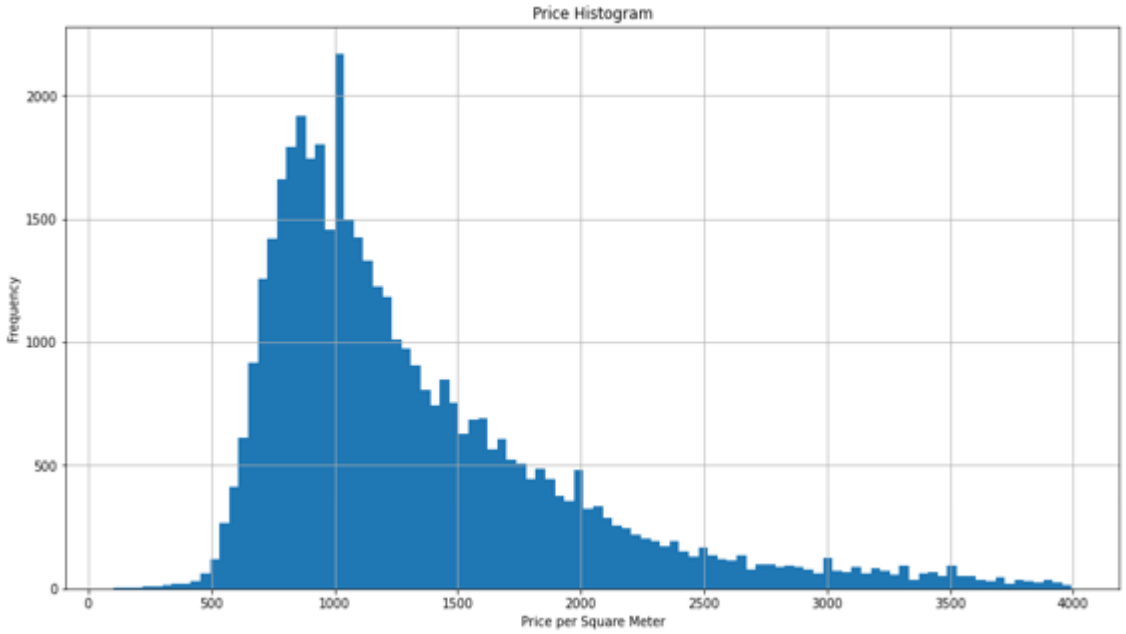

Fig. 1. *The Distribution of the Price of a Square Meter*

Fig. 2 illustrates the distribution of surface areas for apartments in Yerevan. A vast majority of apartments have less than 200 square meters, but some outliers have over 1000 square meters. Detailed analysis of these obvious outliers indicate that they are most often commercial properties that fell in the apartment category in the online platforms due to human error. These outliers are carefully filtered to increase representativeness of the dataset.

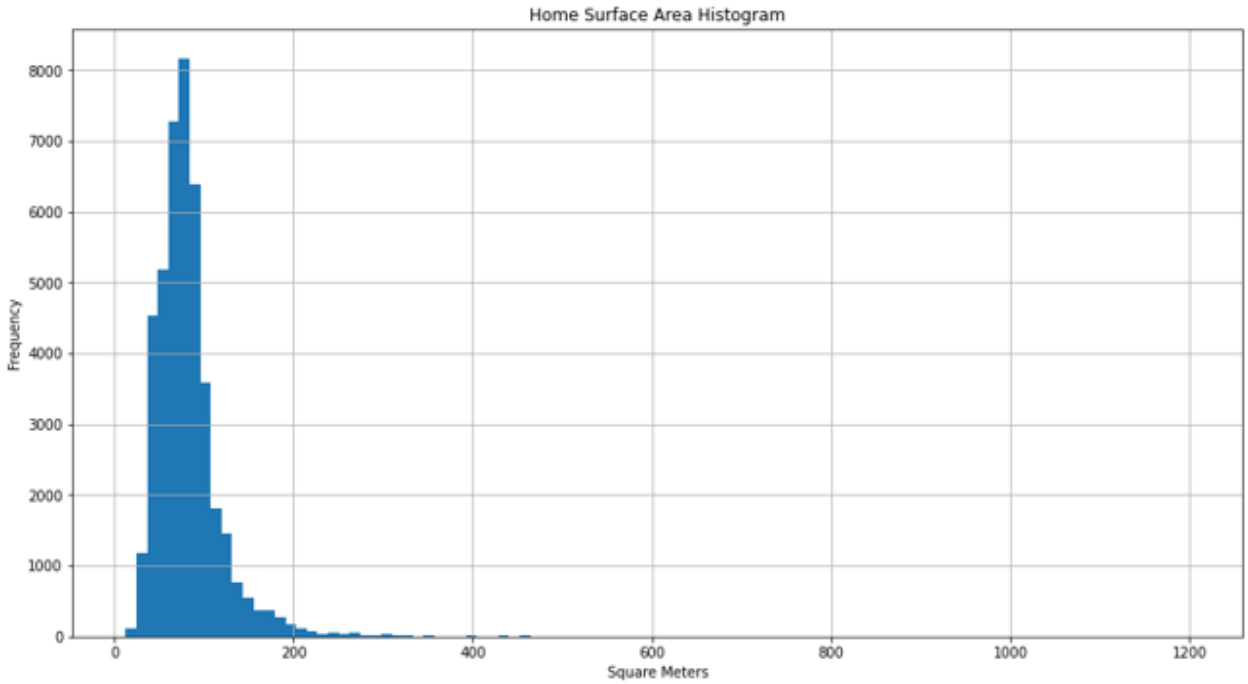

Fig. 2. *The Distribution of the Apartments' Surface Areas*

Fig. 3 illustrates that the most popular number of rooms in an apartment is three. Of note is the fact that there are more apartments that have four rooms than apartments that have one room. Bathroom counts are ordered intuitively in ascending order, with apartment with one bathroom being the most frequent and apartments with five bathrooms being the least frequent.

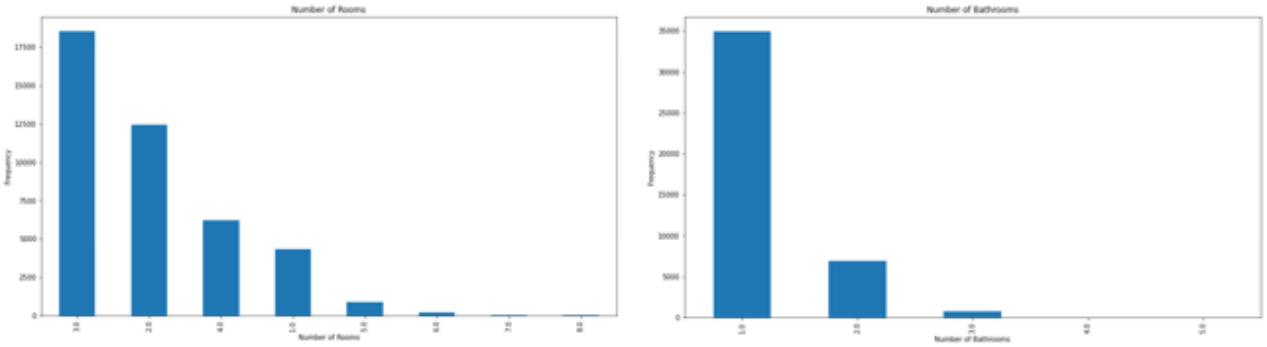

Fig. 3. *Room and Bathroom Count Frequency*

Fig. 4 illustrates that apartment floor frequencies are also ordered largely with respect to an ascending order, with higher floors being increasingly less frequent. Some interesting exceptions to the trend hold. For instance, while the four most common floors are two, three, four and five, apartments on the first floor are in fifth place by frequency. Similarly, apartments on the eighth and ninth floors are more common than those on the seventh floor. According to the Fig. 4, apartment in buildings with five floors are the most common. Second, third, fourth and fifth by frequency are buildings that have nine, four, 14, and 16 floors respectively. The trend is otherwise irregular except for buildings with exceptionally high floor number. In fact, the trend in building floor frequencies is in line with Soviet building standards.

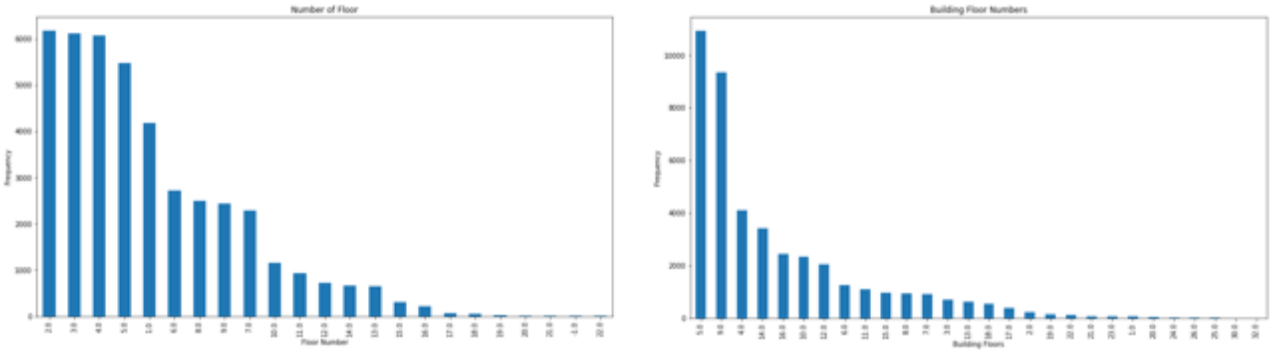

Fig. 4. *Apartment Floor and Building Floors Frequency*

According to Fig. 5, the three main types of buildings are: *panel*, *stone and monolithic*, in that respective order. The top renovation condition category frequencies are largely ordered with respect to a descending level of renovation, with the most common being *"Renovated"*. An exception to this trend is that *"Renovated in Modern style"* and *"Euro renovated"* have low frequencies, which most likely reflects their level of exclusivity. It is important to note that this indicator is somewhat subjective, since home owners often inflate the degree to which a property is renovated to justify higher prices.

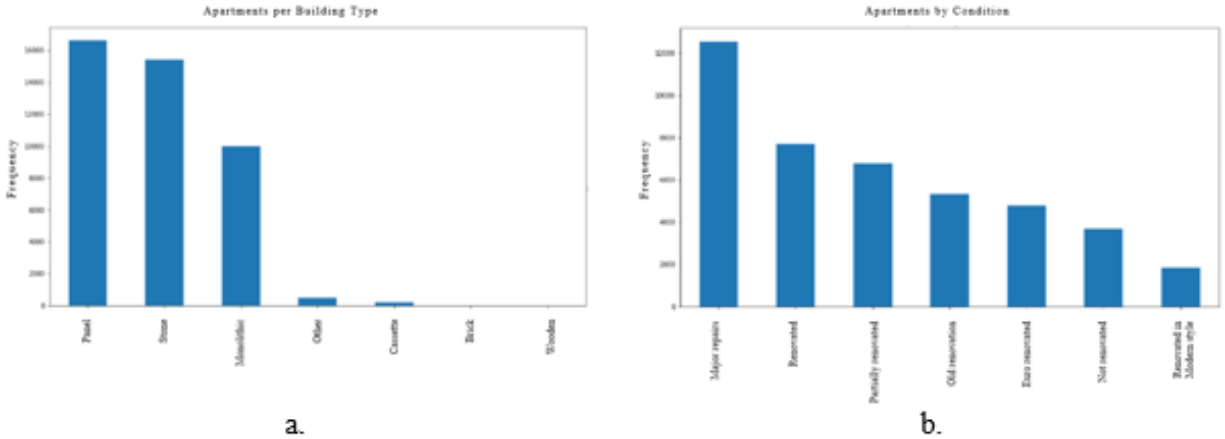

Fig. 5. *Building Type and Apartment Condition*
a. *Building Type*, b. *Apartment Condition*

Fig. 6 illustrates that the center of the city is the highest in both the density and the price of apartments. It is interesting to note that entire sections of the south – eastern portion of the city have almost no apartments for sale, and that those that are for sale have relative low prices.

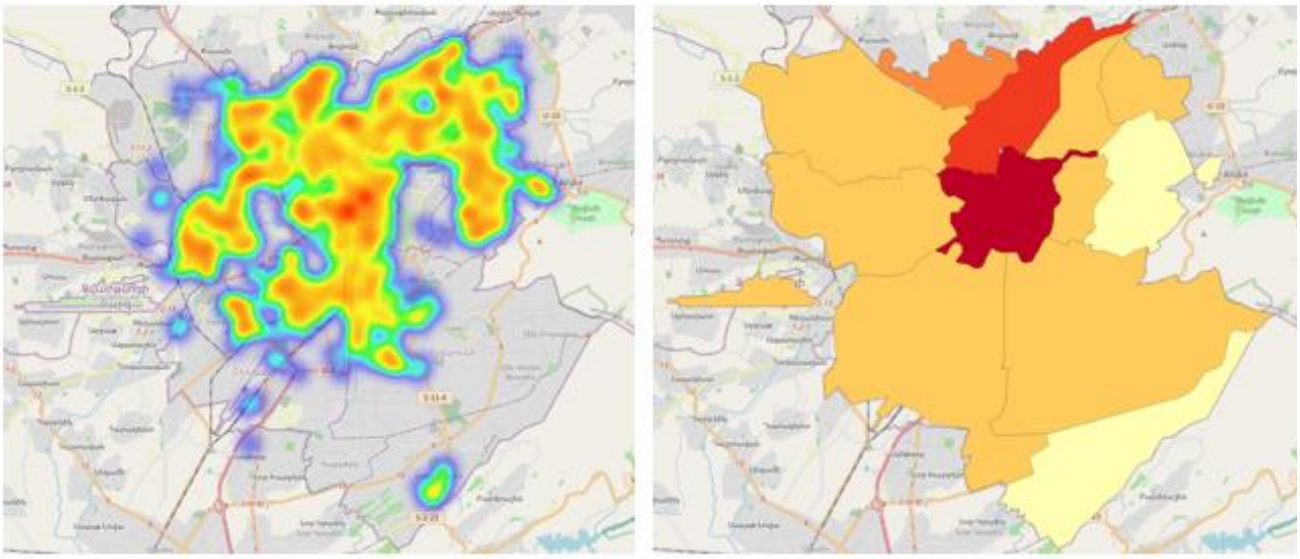

Fig. 6. *Density and Price Heatmaps*

Research methodology

Automated real estate valuation is a popular topic in applied machine learning, and recent work illustrates the effectiveness of various tree-based ensembling techniques for accurate value prediction.

Guliker et al. in their recent work compared the performance of three pricing techniques - linear regression, geographically weighted regression, and extreme gradient boosting - XGBoost) [13]. The performance of XGBoost exceeded that of the other models, with an explained variance of approximately 83% and Mean Absolute Percentage Error (MAPE) of 6.35%.

Metrics to measure the performance of real estate valuation models are also a major topic of discussion since each metric highlights a particular aspect of a model's performance. Steurer et al. suggested ways to assess the effectiveness of several metrics in measuring the performance of machine learning models for automated valuation [15]. A total of 48 metrics were divided into seven classes, and seven final metrics (one per each group) were determined to be the most effective to evaluate automated valuation models. Table 4 describes the final metrics proposed for model assessment where p_n and $\hat{p}_n$ respectively denote actual and predicted price.

Since the proliferation of affordable and granular geospatial data on platform such as OpenStreetMap, Google Maps, Yandex Maps, etc., the use of geographical location features has become increasingly prevalent in automated real estate valuation. Tchuente and Nyawa in their paper evaluate the impact of including granular geographical location features on model performance in the context of the French real estate market [14]. Table 5 illustrates the impact on modelling performance for tree – based ensembling models when including geographic location features data. The paper also illustrates that although neural networks and random forest techniques outperform other algorithms without geographic features, performance gain was larger for random forests and other tree – based methods benefit more than other architecture from the additional data.

Table 4. Metrics to assess model performance

Class	Metric	Formula
Average Bias	Log Median Prediction Error	$LMPE = med\left[ln\left(\frac{p_n}{\hat{p}_n}\right)\right]$
Absolute Difference	Mean Absolute Error	$MAE = \frac{1}{N}\sum_{n=1}^{N}\lvert p_n - \hat{p}_n\rvert$
Absolute Ratio	Max-Min Mean Absolute Prediction Error	$mmMAPE = \frac{1}{N}\sum_{n=1}^{N}\left(\frac{\max(p_n,\hat{p}_n)}{\min(p_n,\hat{p}_n)} - 1\right)$
Squared Ratio	Logarithmic Root Mean Square Error	$LRMSE = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\left[ln\left(\frac{p_n}{\hat{p}_n}\right)\right]^2}$
Squared Difference	Root Mean Square Error	$RMSE = \sqrt{\frac{\sum_{n=1}^{N}(p_n - \hat{p}_n)^2}{N}}$
Percentage Ratio	Max - Min Percentage Error Range	$mmPER(x) = 100\left\lvert\frac{\max(p_n,\hat{p}_n)}{\min(p_n,\hat{p}_n)} - 1\right\rvert > x$
Quaniilc	Inter - Quanile Range in Ratios	$IQRat = ln\left(\frac{p_n}{\hat{p}_n}\right)_{75} - ln\left(\frac{p_n}{\hat{p}_n}\right)_{25}$

Table 5. Performance improvement with Geospatial features for each model

Algorithm	Average Performance Improvement with Geospatial Features
Random Forest	31.7%
Adaboost	40.85%
Gradient Boosting	39.77%

Our approach

Related works in automatic real estate valuation mostly contend that tree – based ensembling models are preferable to other algorithm families, while also documenting the improvement in performance when complementing conventional apartment features with geospatial neighborhood data [7]. We have therefore decided to concentrate our efforts in assessing the difference in performance between tree – based boosting and bagging ensembling models, using geospatial neighborhood data. The sections below provide performance summaries for each case.

XGBoost performance

We have used the *xgboost* Python library to train an XGBoost regressor with the following custom parameters (other parameters are default):

- Number of estimators: 3500,
- Maximum depth: 100.

The learning curves for the model are summarized in Fig. 7. The performance metric that the learning curves track is the RMSE, and the orange and blue curves represent the RMSE on the validation and training sets respectively. XGBoost

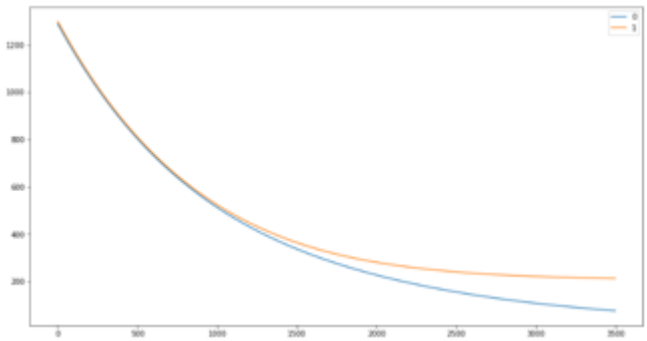

Fig. 7. *RMSE Loss for Training and Validation Sets*

is a sequential ensembling model and the curve illustrates the diminishing learning gains of each additional weak learner. It is evident that RMSE is no longer declining after 3500 estimators, meaning that additional estimators are no longer learning.

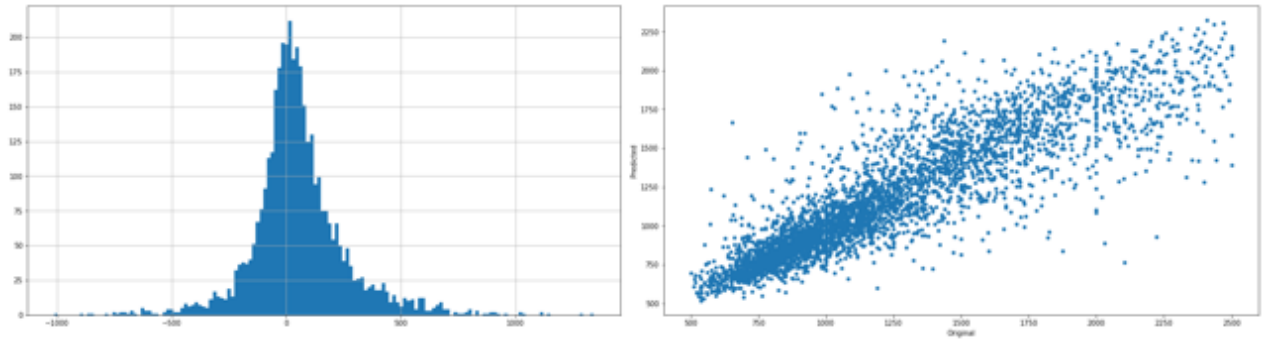

Fig. 8. *Error Histogram and Real vs. Predicted Scatterplot*

The error histogram, presented in Fig. 8, illustrates that the error is highly symmetric and centered around 0, which is an important characteristic of a well-balanced real estate valuation model. The scatter plot of real vs. predicted prices illustrates that a diagonal line has clearly formed, with some dispersion along this diagonal. The scatter plot not only illustrates the fact that test samples are more heavily concentrated around the 800 USD – 1300 USD price range, but also that error tends to increase as prices increase. This is likely a result of there being less training data for more expensive apartments and the fact that apartments which share traits that render them more expensive have a naturally higher variance in price.

Table 6 provides a regression report and accuracy comparison between XGBoost and Random Forest models that includes the metrics documented by Steurer, Hill and Pfeifer. From the Table it becomes clear that XGBoost outperforms its competitor. The model has a mean absolute error of 139.604 and root mean square error of 204.280, thus illustrating the relative impact of outlier errors. The median absolute percentage error is a popular metric to assess model quality. A score of 8.16% indicates that half of the estimates have an error below 8.16%.

Table 6. Model comparison on different evaluation metrics

Metric	XGBoost Scores	Random Forest Scores
Log median prediction error	-0.017	0.03
Mean absolute error	139.609	143.595
Max – Min Mean Absolute error	0.126	0.129
Logarithmic Root Mean Square Error	0.155	0.159
Root Mean Square Error	204.280	212.836
Interquartile Range in Ratios	0.162	0.16
Median Absolute Percentage Error	8.16	8.27

Of particular importance in automated valuation is the relative importance of each feature in the dataset in determining the price of the real estate asset. We have used the Shapley Additive exPlanations (SHAP) approach to obtain feature importance values. The method is based on the Shapley value as discussed in game theory and is often considered the most robust method for feature importance analysis in tree – based ensembling models or machine learning models in general. The SHAP scores can also be used for hedonic breakdown of apartment values as illustrated by L. Chen et al. [16]. According to Fig. 9, District is overwhelmingly the most important factor in predicting the price of a square meter, followed by the surface area of the apartment, whether it is a new construction or not, its renovation condition, building type, etc. It is interesting to note that the neighborhood indicator is not one of the top ten predictor variables.

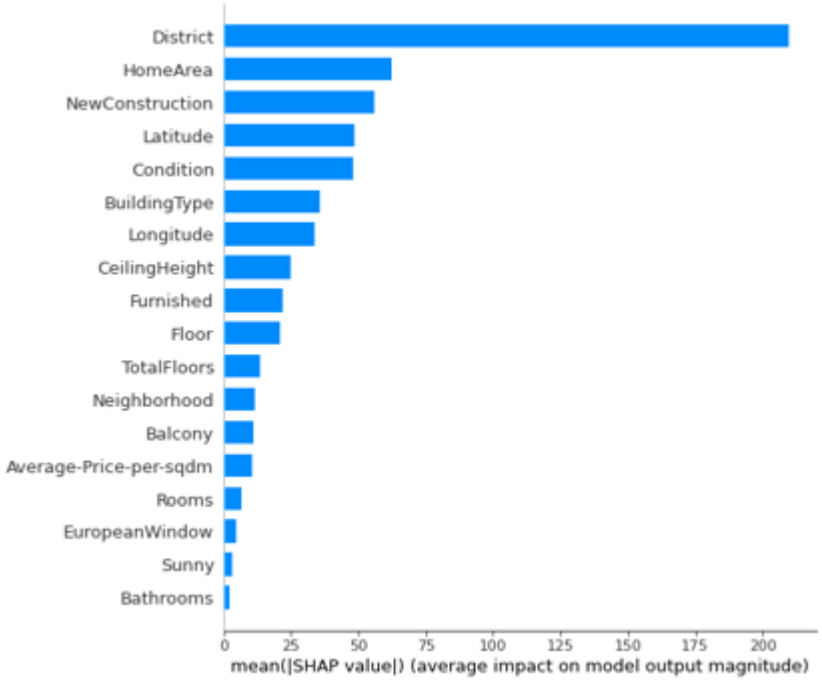

Fig. 9. *Mean SHAP Value*

Conclusion

To sum up, this work aims to provide data driven insights about current state of Armenian real estate market and present a novel approach for predicting house prices in Yerevan, Armenia. We identified the most important features which have an effect on the price of an apartment and elaborated on the explainability of models used for prediction.

We have assessed the performance of two families of tree – based ensembles and determined that XGBoost performs better than Random Forest on data from the Armenian real estate market. In collecting the data, we also developed a stable and scalable data collection pipeline that can function indefinitely to increase the size of our dataset and therefore improve model performance. We envision several future research directions to build on this work.

Firstly, it is highly advised to experiment with integration of computer vision models for object detection and image classification. By analyzing images in apartment advertisements, it is possible to ascertain features that describe furniture, interior design and renovation relying less on subjective descriptions by homeowners or real estate agents. For example, Poursaeed et al. in their work illustrates the effectiveness of convolutional neural networks for estimating the degree of luxury based on interior design, and it is possible to build on this work for more robust results.

Secondly, we can build on the results we obtained for feature importance using SHAP values, by building a hedonic pricing model that will estimate the dollar value of a feature of a property. These results will inform investors, home owners and other stakeholders in the real estate market with regards to the respective value of each feature, such as location, district, surface area or floor number, and will make financial decisions in the real estate sector more data - driven and well informed.

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Received: 06.04.2022
Revised: 22.04.2022
Accepted: 03.06.2022

DOI: https://doi.org/10.54338/27382656-2022.2-013

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FUNDAMENTALS OF METHODOLOGICAL CONTROL OF THE STRENGTH OF COMPOSITE MATERIALS

The idea of this paper is to propose research methods designed for strength analysis of composite materials which are widely used in load-carrying structures. It is shown that the strength analysis and study of composite materials are carried out in two directions – considering them as inhomogeneous composite materials, representing a regular multilayer medium of alternating reinforcement layers and a polymer binder, and the study of the issue of structural strength, in which composites are considered as homogeneous elastic orthotropic bodies, to which the theory of elasticity of anisotropic media is applicable. These approaches enables to represent the composites in the form of a continuous medium and use the methods of the theory of elasticity of anisotropic media in calculating the acting stresses, which makes it possible to use the influence of the elements of manufacturing technology on the physical and mechanical characteristics.

Keywords: *composite materials (CM), strength, stiffness, elasticity*

Introduction

Modern composite materials certainly now constitute one of the most important classes of engineering materials widely used in critical load-carrying structural elements. There are several reasons for this. One is that they offer highly attractive combinations of strength, stiffness, lightness and corrosion resistance. At present, the study of the strength of composite materials is carried out in two directions.

In the works where the first direction is applied [9, 10] composite materials are considered as heterogeneous composites that represent a regular multi-layer medium of alternating reinforcement layers and a polymer binder.

When applying this theory, certainly, difficulties arise in connection with the presence of defects in the manufacture of structures, etc.

In the works where the second direction is used [4, 8], the structural strength study of homogeneous elastic orthotropic bodies, to which the theoretical foundations of the elasticity of anisotropic media are applicable, is becoming widespread. This assumption is based on the fact that the dimensions of the reinforcing filler are negligibly small compared with geometric dimensions of the part's cross-section. Based on this, the composites can be represented as a continuous homogeneous medium. This approach makes it possible to use simple and well-developed methods of the theory of elasticity of anisotropic media when calculating the acting stresses, which enables to take into account the influence of elements of manufacturing technology on the physical and mechanical characteristics of a structure. Orthotropic composite materials are most widely used in load-carrying structures, therefore, the main attention is paid to this issue.

Materials and Methods

The strength characteristics of quasi-homogeneous, nonisotropic materials are derived from a generalized distortional work criterion. For unidirectional composites, the strength is governed by the axial, transverse, and shear strengths, and the angle of fiber orientation. The strength of a laminated composite consisting of unidirectional layers depends on the strength, thickness, and orientation of each constituent layer and the temperature at which the laminate is cured. In the process of lamination, thermal and mechanical interactions are induced which affect the residual stress and the subsequent stress distribution under external load. A

method of strength analysis of laminated composites is delineated using glass-epoxy composites as examples. The validity of the method is demonstrated by appropriate experiments.

Solution of the Problem

It is well known that in the theory of elasticity the stressed state of an anisotropic medium is described by the generalized Hooke's law

$$\sigma_{ix}=\mathrm{C}_{klm}\varepsilon_{im}; \tag{1}$$

where σ_{ix} are the components of the stress tensor; ε_{im} are strain tensor components; C_{klm} are components of the elastic modulus tensor (which is a fourth rank tensor). In this case, the elastic potential is a function of the second degree, invariant with respect to the coordinate degree, then $\mathrm{C}_{iklm} = \mathrm{C}_{ik}$.

For an orthotropic medium, Equation (1) in expanded form can be represented as

$$\left.\begin{aligned}
\sigma_x &=\mathrm{C}_{11}\varepsilon_x+\mathrm{C}_{12}\varepsilon_y+\mathrm{C}_{13}\varepsilon_z,\\
\sigma_y &=\mathrm{C}_{21}\varepsilon_x+\mathrm{C}_{22}\varepsilon_y+\mathrm{C}_{23}\varepsilon_z,\\
\sigma_z &=\mathrm{C}_{31}\varepsilon_x+\mathrm{C}_{32}\varepsilon_y+\mathrm{C}_{33}\varepsilon_z,\\
\tau_{yz} &= C_{44}\nu_{yz},\\
\tau_{zx} &= C_{55}\nu_{zx},\\
\tau_{xy} &= C_{66}\nu_{xy},
\end{aligned}\right\} \tag{2}$$

Hooke's law regarding the components of deformation will be

$$\begin{aligned}
\varepsilon_x &= a_{11}\sigma_x+a_{12}\sigma_y+a_{13}\sigma_z,\\
\varepsilon_y &= a_{21}\sigma_x+a_{22}\sigma_y+a_{23}\sigma_z,\\
\varepsilon_z &= a_{31}\sigma_x+a_{32}\sigma_y+a_{33}\sigma_z,\\
\nu_{yz} &= a_{44}\tau_{yz},\\
\nu_{zx} &= a_{55}\tau_{zx},\\
\nu_{xy} &= a_{66}\tau_{xy},
\end{aligned}$$

where C_{ik} are the elastic constants of the material, a_{ik} are the constants of elastic deformation,

$$a_{ik}=\mathrm{C}_{ik}/\Delta\ ,$$

where Δ is the determinant, composed of the coefficients of the right-hand side of Equation (2), C_{ik} are the corresponding minors of this determinant.

In the expanded form, we will have [1, 9]

$$a_{11}=\left(C_{22}C_{33}-C_{23}^2\right)/\Delta,\quad a_{22}=\left(C_{11}C_{33}-C_{13}^2\right)/\Delta,\quad a_{33}=\left(C_{11}C_{12}-C_{12}^2\right)/\Delta,$$

$$a_{12}=\left(C_{12}C_{33}-C_{13}C_{23}\right)/\Delta;\quad a_{13}=\left(C_{12}C_{23}-C_{13}C_{22}\right)/\Delta,\quad a_{23}=\left(C_{11}C_{23}-C_{13}C_{22}\right)/\Delta,$$

$$a_{44}=C_{44}^{-1};\quad a_{55}=C_{55}^{-1};\quad a_{66}=C_{66}^{-1},$$

where $\Delta=C_{11}C_{22}C_{33}-C_{12}C_{23}^2-C_{12}^2C_{33}-C_{13}^2C_{22}+C_{12}C_{13}C_{23}$.

Physical and technical elastic constants are related by expressions

$$\left.\begin{aligned}
&E_x = a_{11}^{-1} = C_{11} - \left(C_{12}^2 C_{33} + C_{13}^2 C_{22} - 2C_{12}C_{13}C_{23}\right)\left(C_{22}C_{33} - C_{23}^2\right)^{-1};\\
&E_y = a_{21}^{-1} = C_{22} - \left(C_{11}C_{23}^2 + C_{12}^2 C_{33} - 2C_{12}C_{13}C_{23}\right)\left(C_{11}C_{33} - C_{13}^2\right)^{-1};\\
&E_z = a_{33}^{-1} = C_{33} - \left(C_{11}C_{23} + C_{13}^2 C_{22} - 2C_{12}C_{13}C_{23}\right)\left(C_{11}C_{22} - C_{12}^2\right)^{-1};\\
&G_{yz} = a_{44}^{-1} = C_{44}; G_{xz} = a_{55}^{-1} = G_{55}; G_{xy} = a_{66}^{-1} = G_{66}^{-1};\\
&\mu_{xy} = a_{12} / a_{22} = \left(C_{12}C_{33} - C_{13}C_{23}\right)\left(C_{11}C_{33} - C_{13}^2\right)^{-1};\\
&\mu_{xz} = a_{13} / a_{33} = \left(C_{12}C_{23} - C_{13}C_{23}\right)\left(C_{11}C_{22} - C_{12}^2\right)^{-1};\\
&\mu_{yx} = a_{12} / a_{11} = \left(C_{11}C_{33} - C_{13}C_{23}\right)\left(C_{22}C_{33} - C_{23}^2\right)^{-1};\\
&\mu_{zx} = a_{23} / a_{22} = \left(C_{11}C_{23} - C_{13}C_{22}\right)\left(C_{11}C_{33} - C_{13}^2\right)^{-1};\\
&\mu_{yz} = a_{23} / a_{33} = \left(C_{11}C_{23} - C_{13}C_{22}\right)\left(C_{11}C_{22} - C_{12}^2\right)^{-1};\\
&\mu_{zy} = a_{23} / a_{22} = \left(C_{11}C_{23} - C_{13}C_{22}\right)\left(C_{11}C_{33} - C_{13}^2\right)^{-1},
\end{aligned}\right\} \quad (3)$$

where E_x, E_y, E_z, are elastic moduli; G_{yz}, G_{xz}, G_{xy} are shear moduli and $\mu_{xy}, \mu_{xz}, \mu_{yx}, \mu_{zx}, \mu_{yz}, \mu_{zy}$ are Poisson's ratios along the directions of elastic symmetry axes.

In the case of a plane stressed state, the elastic constants can be represented in the form [10, 12]

$$a_{11} = C_{22}\left(C_{11}C_{22} - C_{12}^2\right)^{-1},$$
$$a_{22} = C_{11}\left(C_{11}C_{22} - C_{12}^2\right)^{-1},$$
$$a_{66} = C_{66}^{-1}$$

Then the values of the elastic constants can be represented as:

$$\left.\begin{aligned}
&E_x = C_{11} - C_{12} / C_{22}; E_y = C_{22} - C_{12} / C_{11};\\
&G_{xy} = a_{66}^{-1}; \mu_{yx} = C_{12} / C_{22};\\
&\mu_{yx} = C_{12} / C_{11}
\end{aligned}\right\} \quad (4)$$

It should be noted that the elastic constants of the composite material can be determined by a non-destructive method by the parameters of the propagation of elastic waves [9, 11].

The above Equations (3) and (4) make it possible to calculate the elastic characteristics of the composite material only along the entire elastic symmetry. To determine the elastic characteristics of orthotropic materials in arbitrary directions, the following expressions are proposed [12, 13]

$$E_\varphi = E_x\left(\cos^4\varphi + b'\sin^2\varphi + \lambda\sin^4\varphi\right)^{-1},$$
$$\mu_\varphi = \left[\mu_{xy} - 0.25\left(1 + \lambda - 4b'\right)\sin^2 2\varphi\right]\left[\cos^4\varphi + b'\sin^2\varphi + \lambda\sin^4\varphi\right]^{-1},$$
$$G_\varphi = G_{xy}\left[1 - \left(1 - d\right)\sin^2 2\varphi\right]^{-1}, \lambda = E_x / E_y, b' = \frac{E_x}{E_{45}} - 0.25\left(\lambda + 1\right),$$
$$d = \left(1 + \lambda + 2\mu_{xy}\right)\left(4b' + 2\mu_{xy}\right)^{-1}.$$

By analogy with the anisotropic elastic characteristics in [4], expressions describing the anisotropic strength properties are proposed

$$\sigma_\varphi = \sigma_0\left(\cos^4\varphi + b\sin^2 2\varphi + C\sin^4\varphi\right)^{-1}, \quad (5)$$

where σ_φ is the ultimate tensile or compressive strength in an arbitrary direction; σ_0 is ultimate strength at pure shear at an 45^0 angle to the axis of elastic symmetry

$$c = \sigma_0 / \sigma_{90}; b = a - 0.25(нс); a = \sigma_0 / \sigma_{45} \ . \quad (6)$$

For ultimate strength at pure shear σ_0 in an arbitrary direction in the x,y plane an expression is suggested. On the basis of numerous experiments, good convergence of experimental and calculated data obtained by Equations (5) and (6) has been established. Of considerable interest are the conclusions about the strength made on the basis of the generalized Goldenblatt - Kapnov criterion, which has the below form [6-10]

$$1/\sigma_\varphi^p = \Pi_{11}^0 \cos^2\varphi + \Pi_{22}^0 \sin^2\varphi + \sqrt{\Pi_{11}^0 \cos^4\varphi + \Pi_{2222}^0 \sin^4\varphi + \left(\Pi_{1212}^0 + 0.5\Pi_{1122}^0\right)\sin^2\varphi};$$

$$1/\sigma_\varphi^c = -\Pi_{11}^0 \cos^2\varphi - \Pi_{22}^0 \sin^2\varphi + \gamma\Pi_{11}^0 \cos^4\varphi + \Pi_{2222}^0 \sin^4\varphi + \left(\Pi_{1212}^0 + 0.5\Pi_{1112}^0\right)\sin^2\varphi;$$

$$1/\sigma^+ = \left(\Pi_{11}^0 + \Pi_{22}^0\right)\sin^2\varphi + \sqrt{(\Pi_{1111}^0 - \Pi_{2222}^0 - 2\Pi_{1122}^0)\sin^2 2\varphi + 4\Pi_{1212}^0 \cos 2\varphi};$$

$$1/\sigma^- = -\left(\Pi_{11}^0 - \Pi_{22}^0\right)\sin^2\varphi + \sqrt{(\Pi_{1111}^0 - \Pi_{2222}^0 - \Pi_{1122}^0)\sin^2 2\varphi + 4\Pi_{1212}^0 \cos^2 4\varphi};$$

$$\Pi_{11}^0 = 0.5\left(1/\sigma_\varphi^p - 1/\sigma_0^c\right); \Pi_{22}^0 = 0.5\left(1/\sigma_{90}^p - 1/\sigma_{90}^c\right); \Pi_{1111}^0 = 0.25\left(1/\sigma_0^p - 1/\sigma_0^c\right);$$

$$\Pi_{2222}^0 = 0.25\left(1/\sigma_{90}^p - 1/\sigma_{90}^c\right); \Pi_{1122}^0 = 0.125\left(1/\sigma_0^p - 1/\sigma_0^c\right)^2 + \left(1/\sigma_{90}^p - 1/\sigma_{90}^c\right)^2 - \left(1/\tau_{45}^+ + 1/\tau_{45}^-\right)^2;$$

$$\Pi_{1212}^0 = 0.0625\left(1/\tau_0^+ + 1/\tau_0^-\right)^2.$$

Strength anisotropy according to the Goldenblatt - Kapnov criterion can be used only after strength indicators are experimentally determined.

The dependence of the strength of composite materials on the direction of testing according to [2-5] has the form

$$\sigma_\varphi = \sigma_0 \left(\sqrt{\cos^2\varphi + a^{-2}\sin^2\varphi + 0.5\left(2b^{-2} - a^{-2} - 1\right)\sin^2 2\varphi}\right)^{-1},$$

where $a = \sigma_{90} / \sigma_0; b = \sigma_{45} / \sigma_0$.

Conclusion

In industry, structures are widely used, where strength determines their performance. Among such structures are hollow bodies of revolution (pipes, tanks, cylinders, etc.). Stress states arise in these structures under the action of operational loads. The peculiarity of the composite material role in the structure is to minimize the stress level perpendicular to the plane of the reinforcing layers. Under uniaxial stress of composite material specimens, the axes of which lie in the plane of reinforcement and make an angle α with the axes of elastic symmetry of the material (in relation to the turns directions) the stresses will be equal (Fig.)

$$\sigma_x = \sigma_b \cos^2\alpha; \sigma_y = \sigma_b \sin^2\alpha; \sigma_{xy} = 0.5\sigma_b \sin^2 2\alpha \, .$$

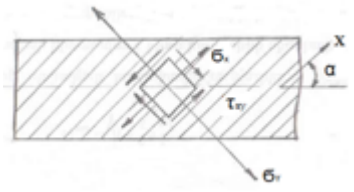

Fig. *Scheme of the stress state in the sample under tension at an angle to the axes of elastic symmetry of the composite material*

If the degree of a composite anisotropy $(\sigma_{90} / \sigma_0; \sigma_{45} / \sigma_0)$ is known, then it is enough, for a given material, to experimentally determine only one strength characteristic, for example, Б0.

At that the ultimate strength in any direction is determined by the Equation (5).

For non-destructive strength tests of composite products, the optimal strength criterion will be that which can be expressed through the anisotropy index determined directly in the product in different structural directions without destroying them.

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Received: 16.12.2021
Revised: 10.02.2022
Accepted: 15.02.2022

DOI: https://doi.org/10.54338/27382656-2022.2-014

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CERAMIC MATERIALS WITH THE USE OF INNOVATIVE SUPPLEMENTS

The use of by-products of the coal industry in the production of wall ceramics is quite relevant. Coal waste is a promising raw material base for the production of ceramic wall materials. Coal sludge is widely used in the production of clay bricks at factories in the Urals and Kazakhstan. The most mastered technology is the use of coal waste as an additive in the production of ceramic products. The use of local waste allows to minimize raw material costs.

Keywords: *Production, raw materials, technogenic waste, technology, coal enrichment, additives.*

Introduction

Currently, the use of coal enrichment waste in the production of building materials is relevant. They are used as additives: in cement, ceramic products, in the production of binders, as well as in road construction. More than 500 mine dumps have formed on the territory of Eastern Donbass (Rostov region) for more than one hundred and fifty years of industrial development, occupying large areas of land.

Coal enrichment waste is a promising raw material base for the production of wall ceramics because they are in fact a ready-made mixture of highly efficient ceramic products, completely possible to replace the primary raw materials. The use of local waste will significantly reduce raw material costs, and will also make it possible to manufacture products with little additional fuel consumption.

Materials and Methods

An analysis of the chemical composition of the products of processing of coal preparation plants showed sufficient stability of the content of Al_2O_3 and SiO_2 oxides, which makes it possible to use these products as ceramic raw materials [1].

The economic efficiency of using coal enrichment waste in the production of ceramic wall products is determined by the reduction in the cost of process fuel, raw materials, as well as the removal and storage of these wastes at coal preparation plants. The maximum economic effect can be achieved by using coal waste at the place of their exit [2-3].

An average grain composition of coal preparation waste is presented in Table 1. It is characterized by a fairly high fineness modulus, and according to this indicator, it can be attributed to the group of sand with increased fineness, with a small amount of a fraction of 0.16-0.315 mm and less than 0.16 mm.

Table 1. Average grain composition of waste coal

Residue name	Residues, % by weight, on sieves					Passage through a sieve with mesh No. 016, % by weight	Fineness modulus
	2.5	1.25	0.63	0.315	0.16		
Partial	8.3	1.8	4.7	11.5	7.3	6.4	3.43
Full	28.3	60.1	74.8	86.3	93.6	–	

According to the chemical composition, coal enrichment wastes do not differ fundamentally from typical clay raw materials and are characterized by AI_2O_3 content from 16 to 22% and potassium oxide content of more than 4%. This is due to the peculiarities of the mineralogical composition. The average chemical composition of coal preparation waste is presented in Table 2.

Table 2. Average chemical composition of coal preparation waste, % by weight

ППП	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	P_2O_5	TiO2
10.27	52-60	16-22	4-7	1-4	1-4	0.2-0.6	3-5	0.2-1.0	0.1-0.3	0.4-1.0

Results and Discussion

The technology for manufacturing laboratory samples is described next. The initial composition of coal enrichment waste was preliminarily dried them in an oven at a temperature of 100 ± 5 ºC during the day due to increased moisture content of 25% compared to the required 18-20%. It was then crushed and sieved into fractions of 0.16-0.63. The composition of the charge consisted of coal enrichment waste from 70 to 90% and clay additives from 10 to 30%. The molding process was executed at a humidity of 6 to 10%. Pressing was carried out according to the technology of rigid extrusion at a pressure of 15 to 25 MPa. The molded samples were dried for 24 hours at a temperature of 100 ± 5ºC. The samples were then fired in a muffle furnace at temperatures from 900 to 1050 ºC for 28 hours.

Below are graphs (Figures 1 and 2) of the dependence of water absorption and strength of fired samples on the degree of grinding of coal preparation waste and firing temperature. The graphs show that at a firing temperature of 1000°C and above, high strength indicators are achieved with a sufficiently low water absorption of the samples.

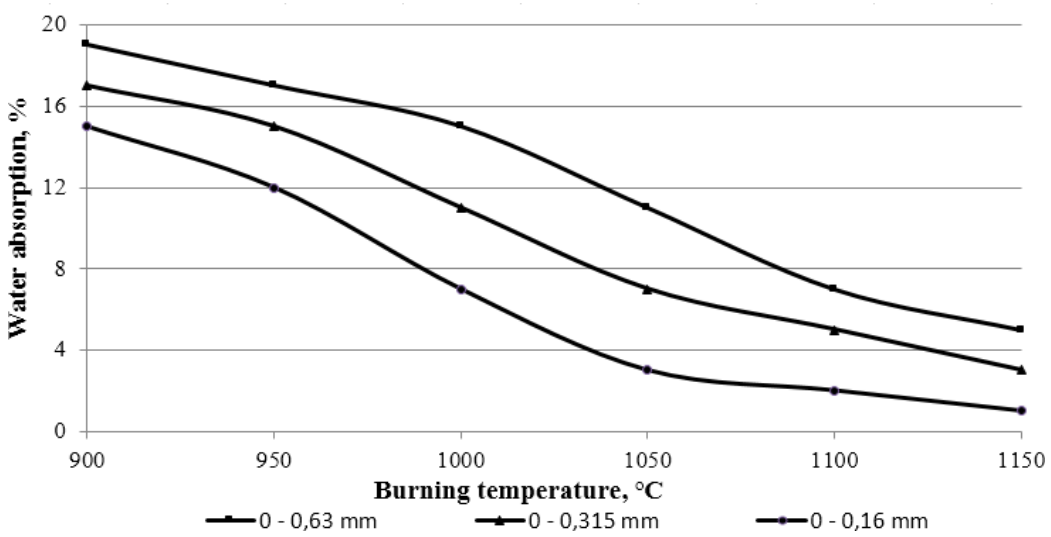

Fig. 1. *Influence of the degree of grinding and firing temperature on the water absorption of samples*

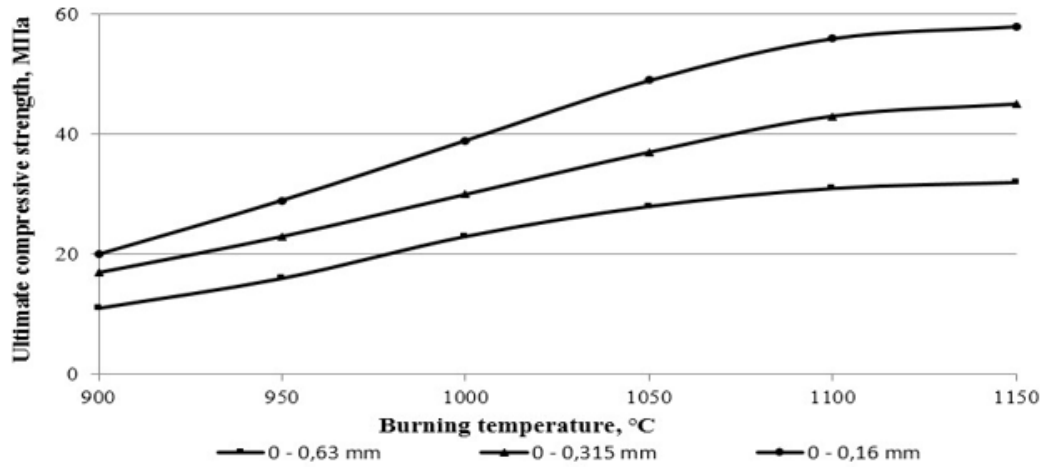

Fig. 2. *Influence of the degree of grinding and firing temperature on the compressive strength*

The use of coal enrichment waste as part of the charge makes it possible to reduce the sensitivity to drying of freshly molded samples. This is explained by the fact that coal enrichment waste is a lean additive. It is obvious that reducing the drying time will lead to lower costs in the manufacture of products. Fuel economy is also achieved due to the fact that the product contains a carbon component, which provides additional firing of the product from the inside. The most important thing is to maintain the gas supply to a temperature of 750°C, the rest of the temperature is provided by burnable coal. In the production of a batch of 1000 pcs. bricks from coal waste defect-free products sums up to 97%, and only 3% with minor defects. And when using clay for 1000 pcs. bricks defect sums up to 23% [3-8]. From this we can conclude that the production of bricks from coal waste is a good substitute for clay raw materials.

Conclusion

The conducted studies have shown that coal enrichment waste is a promising raw material for the production of various wall ceramic products. Their introduction into the raw masses will significantly reduce the cost of firing and, accordingly, the cost of products [9]. Involvement in the production of wall ceramics screenings from the waste heaps of the Eastern Donbass, in our opinion, is technically and economically justified and expedient.

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Received: 11.05.2022
Revised: 24.05.2022
Accepted: 13.06.2022

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